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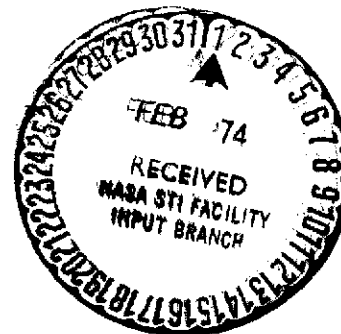
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THE OCTOBER 1973 NASA MISSION MODEL ANALYSIS AND ECONOMIC ASSESSMENT

By Shuttle Utilization Planning Office
Program Development

January 1974



NASA

*George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama*

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16. ABSTRACT <p>This document presents the results of the 1973 NASA Mission Model Analysis performed by Program Development, Marshall Space Flight Center, under the direction of the Mission and Payload Integration Office of NASA Headquarters. The purpose of this analysis was to obtain an economic assessment of using the Shuttle to accommodate the payloads and requirements as identified by the NASA Program Offices and the DoD.</p> <p>The 1973 Payload Model represents a baseline candidate set of future payloads which can be used as a reference base for planning purposes. The cost of implementing these payload programs utilizing the capabilities of the Shuttle system is analyzed and compared with the cost of conducting the same payload effort using expendable launch vehicles.</p> <p>There is a net benefit of 14.1 billion dollars as a result of using the Shuttle during the 12-year period as compared to using an expendable launch vehicle fleet.</p>			
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TABLE OF CONTENTS

	Page
SUMMARY	1
I. INTRODUCTION	3
II. MAJOR GROUND RULES AND ASSUMPTIONS	7
III. PAYLOAD SUMMARY	11
IV. THE SHUTTLE SORTIE PROGRAM	27
V. SORTIE EQUIVALENT PROGRAM	43
VI. PAYLOAD DATA PREPARATION	51
A. Automated Payloads	51
B. Sortie Payloads	52
VII. CAPTURE ANALYSIS	55
A. Shuttle/Tug Capture Analysis	55
B. Expendable Launch Vehicle Capture Analysis	56
C. Reliability Effects	57
D. Flight Hardware Inventory	58
E. Capture Analysis Results — Traffic Model	58
VIII. COST ANALYSIS	71
REFERENCES	75

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LIST OF ILLUSTRATIONS

Figure	Title	Page
1.	Shuttle/Spacelab operating modes	29
2.	Stellar astronomy (pallet only)	31
3.	Solar physics (pallet only)	31
4.	High energy astrophysics	32
5.	Atmospheric and space plasma physics	32
6.	Office of Applications general purpose laboratory no. 1	34
7.	Office of Applications sortie general purpose laboratory no. 2	34
8.	Space processing biology, furnace and levitation	35
9.	Space technology lab.	37
10.	Life science laboratory	38
11.	Sortie equivalent potential modes for mission accomplishment	45
12.	Payload effects application	53
13.	1973 best mix payload summary (986 payloads)	63
14.	1973 Shuttle traffic summary (725 flights)	64
15.	Discounted benefits	72

LIST OF TABLES

Table	Title	Page
1.	NASA Payload Model Comparison (1980-1991)	13
2.	Payload Traffic Summary for Automated Spacecraft	14
3.	Payload Traffic Summary for Sortie Payloads	15
4.	Payload Traffic Summary for Automated Spacecraft Plus Sorties	16
5.	Payload Flight Schedule for Astronomy Program	17
6.	Payload Flight Schedule for Physics Program	18
7.	Payload Flight Schedule for Planetary Exploration Program.	19
8.	Payload Flight Schedule for Lunar Exploration Program.	20
9.	Payload Flight Schedule for Life Sciences Program	20
10.	Payload Flight Schedule for Earth Observations Program . . .	21
11.	Payload Flight Schedule for Earth and Ocean Physics Applications Program	22
12.	Payload Flight Schedule for Communications and Navigation Program	23
13.	Payload Flight Schedule for Space Processing Program	24
14.	Payload Flight Schedule for Space Technology Program	24
15.	Payload Flight Schedule for Non-NASA/Non-DoD Payloads.	25
16.	Sortie Missions, Office of Space Science	30

LIST OF TABLES (Continued)

Table	Title	Page
17.	Sortie Missions, Office of Applications	33
18.	Sortie Missions, Office of Aeronautics and Space Technology	36
19.	Sortie Missions, Office of Manned Space Flight	36
20.	Sortie Mission, Non-NASA/Non-DoD Sortie Payloads	39
21.	Total Sortie Payloads NASA and Non-NASA.	40
22.	NASA Sortie Payload Summary	41
23.	Sortie Missions Converted to Equivalent Mode.	46
24.	Sortie Equivalent Space Station Operations	46
25.	Assumed Sortie Equivalent Approach (Automated Spacecraft)	47
26.	Assumed Sortie Equivalent Approach (Space Station)	48
27.	Sortie Equivalent, Space Station Equivalent, Dedicated RAM Payloads	49
28.	Shuttle and Tug Traffic Summary	61
29.	Sortie Flight Summary	62
30.	Shuttle Launched Payload Traffic Summary Best Mix of Payloads NASA, Non-NASA & DoD	65
31.	Payload Type Summary (Best Mix)	66
32.	STS Flight Hardware.	67

LIST OF TABLES (Concluded)

Table	Title	Page
33.	Expendable Launch Vehicle Traffic Summary, Assigned Due to WTR Availability and Shuttle Buildup Rate	68
34.	Expendable Launch Vehicle Traffic Summary, Best Mix Expendable Payloads, NASA/Non-NASA	69
35.	Expendable Launch Vehicle Traffic Summary, Best Mix Expendable Payloads, NASA/Non-NASA/DoD	70
36.	1973 Mission Model, Summary Cost Comparison	73
37.	1973 Mission Model, Summary Benefit Analysis	73
38.	1973 Mission Model, Automated Missions Benefit Analysis	74
39.	1973 Mission Model, Sortie Benefit	74
40.	1973 Mission Model, Summary Benefit Analysis Automated and Sortie	74

1973 NASA MISSION MODEL ANALYSIS AND ECONOMIC ASSESSMENT

SUMMARY

This report is a summary of the results of the 1973 Mission Model Analysis to compare the cost of conducting various payload programs with the Shuttle to the cost of performing them with expendable launch vehicle systems.

The comparison was based on delivering payloads during a 12-year period beginning in 1980 and ending in 1991. The candidate payloads included those to be built by NASA, U.S. commercial firms, and certain foreign organizations. In addition, the DoD payloads planned during 1980-1991 were included. The NASA and non-NASA payloads are described in the document entitled 1973 NASA Payload Model, dated October 1973. The DoD data are based on the August 1971, Option B, DoD Payload Model.

The payloads were designed to include low cost effects (where economical), retrieval, and reuse whenever possible. There were 986 Shuttle payloads, consisting of both automated and sortie payloads. The automated ones included both low earth orbit and high altitude payloads (requiring use of a Tug). It was determined that 821 payloads launched on expendable launch vehicles would be approximately equivalent to the 986 Shuttle delivered ones.

The results of the capture analysis indicated that it would take 725 Shuttle flights to meet the requirements of the DoD and NASA/non-NASA payload programs. This takes into account the fact that the Shuttle can accommodate more than one payload per flight and can retrieve payloads. There were 685 launches required to deliver the equivalent expendable launch vehicle payloads. Both cases utilize their respective "best mix" payloads.

Because of the Shuttle's capability to retrieve and reflly refurbished payloads and due to the lower transportation costs per flight, use of the Shuttle resulted in a benefit of 14.1 billion dollars for the 12-year period.

I. INTRODUCTION

This document presents the results of the 1973 NASA Mission Model Analysis performed by Program Development, Marshall Space Flight Center, under the direction of the Mission and Payload Integration Office of NASA Headquarters. The purpose of this analysis was to finalize the economic assessment of the Shuttle based on the payloads requirements identified by the NASA Program Offices and the DoD.

The October 1973 NASA Payload Model document, Reference 1, provides a projection of possible future payloads for the Shuttle era based upon current Agency payload planning and user community interest. The cost of implementing this payload program utilizing the capabilities of the Shuttle system is then analyzed and compared to the cost of implementing the same payload effort using expendable launch vehicles. This analysis provides a basis for determining the cost effectiveness of the Space Shuttle system for space exploration and application in the future.

This analysis was accomplished using the basic ground rules, engineering analysis methodology, and parametric cost models developed in the Mathematica-Aerospace analysis completed in 1971 as documented in References 2 and 3. The data base leading to low cost payload design concepts was expanded from that provided by Lockheed Missiles and Space Company in the initial Payloads Effects Study to include the results of a more recent study as outlined in Reference 4. Modifications and improvements to the techniques were made by MSFC where further knowledge and/or improved capabilities existed.

In conducting the 1973 analysis, it was also considered desirable to make several modifications in the methodology for determining least program costs for the expendable launch vehicle case. This included:

1. Incorporating low cost design approaches, where practical, into payload designs flown on expendable launch vehicle systems.
2. Where performance and geometry permitted, multiple payloads were grouped for delivery on a single expendable launch vehicle flight.
3. The cost saving derived from recovery of solid rocket motors used with the expendable launch fleet also were incorporated in the analysis.

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The 1973 Mission Model Analysis is based upon the most current and comprehensive information available, both in terms of the payload program to be flown and the transportation system used for its implementation. It is emphasized that the 1973 Payload Model assumed in this analysis is a tableau of a situation undergoing continuous revision and update consistent with the dynamic nature of national priorities and space objectives of NASA and the user community. Consequently, it should not be considered an Agency plan, but rather represents our best current projection of payload activities for the Shuttle era. The Payload Model does provide a baseline for a number of study activities concerned with making space operations routine, simple, and economical. It also assists in focusing attention on the requirements that the payload carriers and supporting equipment must meet to effectively and efficiently accommodate the Payload Model.

A major impetus for the update of the Mission Model was the desire to apply new concepts on the use of the Shuttle. Two years of intensive study by NASA, contractors, and the user community, including foreign space organizations, have introduced a number of new approaches in the areas of payload design and Shuttle operations. Activities such as the Goddard Workshop carried out in the summer of 1972, Shuttle Payload Planning Working Groups in the various disciplines and the NASA-sponsored Woods Hole Summer Study of 1973 all contributed to this increased understanding of Shuttle utilization.

One of the most significant results of these activities was improved definition of the sortie mode of operation and the advantages offered to experimenters by this facility. The sortie mode provides a new dimension in low cost design, reuse of equipment, experimenter involvement and flexibility of operation. Consequently, over one-third of the payloads in the 1973 Payload Model make use of this mode of operation.

The 1973 Mission Model Analysis also took into account better definition of the Space Transportation System elements than was available in the 1971 analysis. Shuttle performance and cost estimates have been refined and Tug characteristics better defined. These are all identified in the guidelines governing the analysis. The analysis also incorporated the Spacelab design evolved by ESRO through a series of preliminary design study efforts carried out over the past two years.

The 1973 Mission Model Analysis provides an estimate of the makeup of future space payloads and identifies the benefits of accommodating these payloads with the Shuttle system as compared to the expendable launch vehicle fleet. The results of this analysis are contained in the following sections:

- II. Major Ground Rules and Assumptions
- III. Payload Summary
- IV. The Shuttle Sortie Program
- V. Sortie Equivalent Program
- VI. Payload Data Preparation
- VII. Capture Analysis
- VIII. Cost Analysis

II. MAJOR GROUND RULES AND ASSUMPTIONS

The data origins, conditions, and constraints for the 1973 Mission Model Analysis are listed below. The ground rules and assumptions fall within the general categories of payloads, payload carriers, facilities, and cost/capture analysis.

Payload Model

- The Payload Model for NASA Shuttle missions in the 1980-1991 period assumed an average NASA level budget of \$3.3 B (1972 constant dollars).
- Analysis based on NASA/non-NASA/non-DoD payloads defined in the 1973 NASA Payload Model dated October 1973.
- DoD Payload Model is August 1971 (updated), Option B.

Automated Payloads

- Program content for NASA payloads provided by NASA discipline offices.
- Foreign program content provided by NASA discipline offices and reviewed by ESRO.
- Non-NASA/non-DoD program content synthesized from discipline office interpretation of current user planning.
- Payload designs and costing utilize data base resulting from LMSC, TRW, and Aerospace analysis.
- Redesign of payloads for Shuttle utilization will neither degrade nor upgrade mission objectives.

Spacelab Payloads

- NASA Spacelab payloads derived from NASA/scientific community working groups and coordinated by the Joint User Requirements Group (JURG).
- Foreign Spacelab missions provided by ESRO.
- Thirty-day Spacelab missions begin no earlier than CY-1983.

- Three Spacelab/Shuttle configurations considered for capture (lab only, lab/pallet, and pallet only).
- Spacelab payloads configured to the expendable launch vehicle mode based on the most effective approach to accomplish the same scientific objectives.
- Spacelab equivalent for the expendable mode accomplished by:
 - a. Three-man space station (available in CY-1980).
 - (1) Core station (crew, power, and general purpose lab).
 - (2) Research and Applications Modules (RAM).
 - (3) Ninety-day crew rotation.
 - (4) Experiment time equivalent to Spacelab/Shuttle time.
 - (5) T-IIIM/Big "G" logistics support.
 - b. Automated payloads.
 - c. Sounding rockets.
 - d. Balloons.

Space Shuttle

- Configuration and capability consistent with latest Shuttle design concept (2 percent c.g. and 32,000-pound landing weight limit).
- Shuttle buildup rate: 14 flights in 1980, 36 flights in 1981, 50 flights in 1982.
- IOC of Shuttle assumed late CY-1979.
- Turnaround time on ground assumed to be 2 weeks per Shuttle.
- Shuttle reliability consistent with Aerospace Corporation ground rules used in 1971 Mission Model Analysis.

Space Tug

- Retrievable (interim) Tug IOC late CY-1980; full performance Tug with payload retrieval IOC late CY-1983.
- Turnaround time on ground assumed to be same as Shuttle (2 weeks).
- Tug reliability consistent with Aerospace Corporation ground rules used in 1971 Mission Model Analysis.

Spacelab

- Spacelab developed by Europeans.
- Availability assumed at Shuttle IOC.
- Configuration and performance consistent with latest Spacelab design.
- Docking module required for Spacelab missions (except pallet only missions).
- Turnaround time on ground dependent on experiment complement and flight configuration.

Expendable Launch Vehicles

- For automated missions: Scout, TAT, Atlas/Centaur, Titan derivatives.
- Direct operating costs reflect rate effects.

Launch Sites

- ETR available as required for entire time span.
- WTR available in late CY-1982.
- 3. No polar launches from ETR.

Cost/Capture Analysis

- Low cost effects incorporated where applicable into payload designs for use for both the expendable launch vehicles and Shuttle cases.
- Titan solid rocket motors to be recovered and reused in expendable launch vehicle case.
- Capture analysis restrained by Shuttle and Tug delivery/retrieval capability, cargo volume, c.g. limit, landing weight limit, ground turnaround time, Shuttle overhaul, etc.
- 1980 through 1991 time span assumed for analysis.
- Post-1991 (1992-1998) payload model synthesized to avoid program "tailoff."
- Payload multiples permitted in both Shuttle and expendable cases.
- DoD payloads not to be combined with non-DoD payloads.
- Costs include reliability effects of vehicles, carriers, and payloads.
- All costs in 1972 constant dollars.
- Shuttle, Tug, and Spacelab developments, and unit and operations costs provided by program offices.

III. PAYLOAD SUMMARY

This section contains data which compare the 1971 and 1973 Payload Models for the Shuttle era. It includes the payload schedules from the 1973 Payload Model for all NASA programs and for non-NASA users with the exception of DoD. Schedules from the scientific disciplines encompassing all NASA programs and anticipated requirements of the user community are included. The payload schedules are a reference set of future payload activities which serve as a basis for identifying requirements, and effectively utilizing the Shuttle, Space Tug, Spacelab, and all payload carriers which support science and applications objectives of the future. For more detailed information on these payloads, refer to the document cited in Reference 1.

For the NASA portion of this Model, the projections are based on user requirements identified through dedicated study activities and through contacts with the science and applications communities. For the non-NASA portion, the projections represent NASA's estimate of anticipated user needs based on past experience, contractual commitments, and dedicated study activities. The foreign sortie estimates are based directly on a model submitted by ESRO. While not included in these schedules, the DoD model was submitted directly to NASA by DoD for the purpose of the Mission Analysis. It is based on the August 1971 (Option B) update of the March 1971 DoD model used in the preliminary release of the NASA 1973 Mission Model Analysis and represented the best data available for assessment at the time this analysis was initiated.

Table 1, which is a comparison of the October 1973 NASA Payload Model with the 1971 Model, highlights the changes in NASA's projection of future payloads. For example, the number of life sciences and space technology automated spacecraft increased with the removal of the Space Station from the model. Also, the number of sortie flights increased significantly in all disciplines. The DoD and non-NASA Payload Models also changed with the total number of payload flights increasing. A non-NASA sortie program is defined in the current Model. The more significant Model changes are:

1. Approximately 15 percent reduction in automated spacecraft.
2. Significant increase in planetary program.
3. Automated Lunar program added.
4. Major increase in sortie missions.

5. Space Station deleted.
6. DoD program based on August 1971 revision (Option B).
7. Non-NASA payloads increased.
 - a. Post 1974 Comm/Nav program transferred from NASA to Non-NASA model.
 - b. Material processing and foreign sortics added.

The payload descriptors were derived predominantly from the Shuttle Systems Payload Description (SSPD) study data published in July 1973. This payload descriptive data served as the basis for this analysis.

The number of payloads to be delivered during the 1980-1991 time frame are summarized in Tables 2 through 4. Table 2 is a list for the automated payloads; Table 3 is a list of sortic payloads; and Table 4 is a summary of Tables 2 and 3. Tables 5 through 15 show the individual payload flight schedule for each payload discipline.

TABLE 1. NASA PAYLOAD MODEL COMPARISON (1980-1991)

	1971 Model	Oct. 1973 Model
Explorer Class	88	86
Science	(60)	(34)
Applications	(28)	(28)
Life Sciences	(0)	(24)
Intermediate Class	115	91
Science	(12)	(16)
Applications	(84)	(28)
Planetary	(19)	(41) ^b
Life Sciences	(0)	(0)
Space Technology	(0)	(6)
Large Observatories	71	44
Spacecraft	(9)	(13)
Revisits	(62)	(31)
Sorties	97 ^a	286
Science	(48)	(110)
Applications	(31)	(59)
Life Sciences	(5)	(28)
Space Processing	(7)	(43)
Space Technology	(6)	(46)
Space Station	53	0
Station Modules	(14)	
Logistics	(33)	
Lab Modules	(6)	
Total NASA	327	507
DoD March 1971 "B" Model	281	304
Non-NASA	128	175
Spacecraft	(128)	(125)
Sorties	(0)	(50)
Total Gross Model	736	986

a. Not included in the cost benefit analysis.

b. Includes seven automated Lunar missions.

TABLE 2. PAYLOAD TRAFFIC SUMMARY FOR AUTOMATED SPACECRAFT

NASA	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	TOTAL
ASTRONOMY	5	2	4	5	4	7	6	7	5	6	5	6	62
PHYSICS	2	3	1	2	3	1	2	3	4	3	4	4	32
PLANETARY	2	7	0	3	4	5	5	2	0	2	2	2	34
LUNAR	0	0	0	0	1	0	1	1	1	1	1	1	7
EARTH OBSERVATIONS	3	4	3	3	2	4	2	6	2	4	2	4	39
EARTH AND OCEAN PHYSICS	2	4	2	0	0	1	4	0	0	0	4	0	17
COMMUNICATIONS / NAVIGATION	0	0	0	0	0	0	0	0	0	0	0	0	0
LIFE SCIENCES	2	2	2	2	2	2	2	2	2	2	2	2	24
SPACE PROCESSING	0	0	0	0	0	0	0	0	0	0	0	0	0
SPACE TECHNOLOGY	1	0	1	0	1	0	1	0	1	0	1	0	6
TOTAL NASA	17	22	13	15	17	20	23	21	15	18	21	19	221
NON-NASA - NON-DOD													
COMMUNICATIONS / NAVIGATION	6	6	5	8	6	6	6	3	9	5	9	4	73
EARTH OBSERVATIONS	2	4	4	2	2	3	3	3	7	4	5	4	43
EARTH AND OCEAN PHYSICS	0	0	0	0	0	0	3	0	3	0	3	0	9
TOTAL NON NASA	8	10	9	10	8	9	12	6	19	9	17	8	125
TOTAL DOD	34	18	21	32	28	25	23	25	25	25	26	22	304
TOTAL AUTOMATED S / C	59	50	43	57	53	54	58	52	59	52	64	49	650

TABLE 3. PAYLOAD TRAFFIC SUMMARY FOR SORTIE PAYLOADS

NASA	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	TOTAL
ASTRONOMY	1	2	3	4	5	7	7	6	6	6	5	6	58
PHYSICS	1	2	3	3	5	5	6	5	6	5	6	5	52
EARTH OBSERVATIONS	2	2	2	2	2	2	2	2	2	2	2	2	24
SPACE PROCESSING	1	2	4	4	4	4	4	4	4	4	4	4	43
EARTH AND OCEAN PHYSICS	2	2	2	2	2	2	2	2	2	2	2	2	24
COMM. & NAV.	0	1	1	1	1	1	1	1	1	1	1	1	11
LIFE SCIENCE	2	2	2	2	2	2	2	2	3	3	3	3	28
SPACE TECHNOLOGY	2	4	4	4	4	4	4	4	4	4	4	4	46
TOTAL	11	17	21	22	25	27	28	26	28	27	27	27	286
NON/NASA—NON/DOD													
SPACE MANUFACTURING	0	0	0	0	0	1	2	1	2	1	2	1	10
FOREIGN SORTIE	2	3	3	4	3	4	3	4	3	4	3	4	40
TOTAL	2	3	3	4	3	5	5	5	5	5	5	5	50
SUM TOTAL	13	20	24	26	28	32	33	31	33	32	32	32	336

TABLE 4. PAYLOAD TRAFFIC SUMMARY FOR
AUTOMATED SPACECRAFT PLUS SORTIES

	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
NASA AUTOMATED	17	22	13	15	17	20	23	21	15	18	21	19	221
NASA SORTIE	11	17	21	22	25	27	28	26	28	27	27	27	286
NASA TOTAL	28	39	34	37	42	47	51	47	43	45	48	46	507
NON-NASA AUTOMATED	8	10	9	10	8	9	12	6	19	9	17	8	125
NON-NASA SORTIE	2	3	3	4	3	5	5	5	5	5	5	5	50
NON-NASA TOTAL	10	13	12	14	11	14	17	11	24	14	22	13	175
DOD	34	18	21	32	28	25	23	25	25	25	26	22	304
SUM TOTAL	72	70	67	83	81	86	91	83	92	84	96	81	986

TABLE 5. PAYLOAD FLIGHT SCHEDULE FOR
ASTRONOMY PROGRAM (AST)

Payload Code	Payload	CY	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	Total
	<u>Automated Spacecraft</u>																					
AST-1	Explorers		②	①	②	①	①	②	1	2	1	1	2	1	2	1	2	1	1	1	1	26
AST-2	Orbiting Solar Obs.			①																		1
AST-3	Solar Physics Mission																					7
AST-4	High Energy Astr. Obs. A-C					①	①	①														4
	<u>Large Observatories</u>																					
AST-5	High Energy Astr. Obs. D+E Revisits																					4
AST-6	Large Space Telescope Revisits																					5
AST-7	Large Solar Obs. Revisits																					3
AST-8	Large Radio Obs. Revisits																					9
AST-9	Focusing X-Ray Telesc. Revisits																					1
																						6
																						1
																						3
																						4
	Total Autom.		2	2	2	1	2	4	2	5	2	4	5	4	7	6	7	5	6	5	6	77
	<u>Sortie Payloads</u>																					
AST-10	Stellar																					33
AST-11	Solar																					25

Notes:

○ Approved and Ongoing

TABLE 6. PAYLOAD FLIGHT SCHEDULE FOR
PHYSICS PROGRAM (PHY)

Payload Code	Payload	CY	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	Total
	<u>Automated Spacecraft</u>																					
PHY-1	Explorers		②	①	②	①	②	①	2	1	2	1	1	2	1	1	1	2	2	2	2	29
PHY-2	Grav. & Rel. Sat.									1			1			1					1	4
PHY-3	Environ. Perturb. Sat.										1			1			1			1		4
PHY-4	Helio. & Interstel. S/C																	1				1
	<u>Large Observatories</u>																					
PHY-5	Cosmic-Ray Laboratory Revisits																					1 4
	Total Autom.		2	1	2	1	2	1	2	2	3	1	2	3	1	2	3	4	3	4	4	43
	<u>Sortie Payloads</u>																					
PHY-6	High Energy Astrophysics									1	1	2	2	2	2	2	2	2	2	2	2	22
PHY-7	Atmospheric and Space Physics										1	1	1	3	3	4	3	4	3	4	3	30

Note:

○ Approved and Ongoing

TABLE 7. PAYLOAD FLIGHT SCHEDULE FOR
PLANETARY EXPLORATION PROGRAM (PL)

Payload Code	Payload	CY	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	Total
<u>Approved Programs</u>																						
PL-1	Mariner Venus/Mercury		①																			1
PL-2	Pioneer Jupiter Flyby		①			①																0
PL-3	Helios			①																		2
PL-4	Viking 75				②																	2
PL-5	Mariner Jup/Sat 77					②																2
<u>Inner Planets</u>																						
PL-6	Viking Orbiter/Lander 79								1													1
PL-7	Surface Sample Return													2								2
PL-8	Satellite Sample Return																			1	1	2
PL-9	Pioneer Venus							2														2
PL-10	Inner Pl. Follow-On									1	2		1			1						5
PL-11	Venus Radar Mapper												2									2
PL-12	Venus Buoyant Station																					2
PL-13	Mercury Orbiter													2								2
PL-14	Venus Large Lander																2					2
<u>Outer Planets</u>																						
PL-15	Mariner Jup/Uranus Flyby								2													2
PL-16	Pioneer Jup/Uranus Flyby (Uranus Probe)								1													1
PL-17	Pioneer Saturn Probe									1												1
PL-18	Pioneer Sat/Uranus Flyby (U Probe)										1											1
PL-19	Mariner Jupiter Orbiter										2											2
PL-20	Pioneer Jupiter Orbiter													2								2
PL-21	Mariner Saturn Orbiter														2							2
PL-22	Mariner Uranus/Nep Flyby															2						2
PL-23	Jupiter Sat. Orb/Lander																			1	1	2
<u>Comets & Asteroids</u>																						
PL-24	Dual Comet Flyby					1																1
PL-25	Encke Slow Flyby								1													1
PL-26	Encke Rendezvous										2											2
PL-27	Halley Flyby														1							1
PL-28	Asteroid Rendezvous															2						2
Total			1	1	2	2	2	2	5	2	7	0	3	4	5	5	2	0	2	2	2	49

Note: ○ Approved and Ongoing
△ Launched

TABLE 8. PAYLOAD FLIGHT SCHEDULE FOR
LUNAR EXPLORATION PROGRAM (LUN)

Payload Code	Payload	CY	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	Total
	<u>Automated Spacecraft</u>																					
LUN-1	Lunar Polar Orbiter								1													1
LUN-2	Lunar Orbiter													1		1						2
LUN-3	Lunar Rover																1	1				2
LUN-4	Lunar Halo																		1			1
LUN-5	Lunar Sample Return																			1	1	2
	Total								1					1		1	1	1	1	1	1	8

TABLE 9. PAYLOAD FLIGHT SCHEDULE FOR
LIFE SCIENCES PROGRAM (LS)

Payload Code	Payload	CY	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	Total
	<u>Automated Spacecraft</u>																					
LS-1	Life Sciences Research Module						1		1	2	2	2	2	2	2	2	2	2	2	2	2	26
	Total Autom.						1		1	2	2	2	2	2	2	2	2	2	2	2	2	26
	<u>Sortie Payloads</u>																					
LS-2	Laboratory and Carry-On Payloads									2	2	2	2	2	2	2	2	3	3	3	3	28

TABLE 10. PAYLOAD FLIGHT SCHEDULE FOR
EARTH OBSERVATIONS PROGRAM (EO)

Payload Code	Payload	CY	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	Total
	<u>Automated Spacecraft</u>																					
EO-1	Earth Resources Tech. Sat.					①																1
EO-2	NIMBUS			①			①															2
EO-3	Earth Observatory Sat.							1	1	1	1	1	1	1	2	1	1	1	1	1	1	15
EO-4	Syn. Earth Obs. Sat.										1		1		1		2		2		2	9
EO-5	Special Purpose Sat.					1	1	1	2	2	2	1	1	1	1	1	1	1	1	1	1	19
EO-6	TIROS						①					1					1					3
EO-7	Syn. Meteorological Sat.		①	①				1									1					4
	Total Autom.		1	2		2	3	3	3	3	4	3	3	2	4	2	6	2	4	2	4	53
	<u>Sortie Payloads</u>																					
EO-8	(Weather Simulation Lab., Sensor R&D)									2	2	2	2	2	2	2	2	2	2	2	2	24

Note:

○ Approved and Ongoing

TABLE 11. PAYLOAD FLIGHT SCHEDULE FOR
EARTH AND OCEAN PHYSICS APPLICATIONS PROGRAM (EOP)

Payload Code	Payload	CY	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	Total
	<u>Automated Spacecraft</u>																					
EOP-1	Geodetic Earth Orbiting Sat.			①																		1
EOP-2	Laser Geodynamic Sat.					①																1
EOP-3	SEASAT						1					1										2
EOP-4	GEOPAUSE								1			1										2
EOP-5	Grav. Gradiometer									1												1
EOP-6	Mini-Laser Geodynamic Sat.									1					1							2
EOP-7	GRAVSAT								1													1
EOP-8	Vector Magnetometer Sat.										3					3				3		9
EOP-9	Magnetic Monitor Sat.										1					1				1		3
	Total Autom.			1		1	1		2	2	4	2			1	4				4		22
	<u>Sortie Payloads</u>																					
EOP-10	(Earth and Ocean Dynamics Experiments)									2	2	2	2	2	2	2	2	2	2	2	2	24

Notes:

○ Approved and Ongoing

TABLE 12. PAYLOAD FLIGHT SCHEDULE FOR
COMMUNICATIONS AND NAVIGATION PROGRAM (C/N)

Payload Code	Payload	CY	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	Total
C/N-1 C/N-2	<u>Automated Spacecraft</u>																					
	Applic. Tech. Sat.			①																		1
	Coop. Applic. Sat.				①																	1
	Total			1	1						0			0		0	0	0				2
CN/3	<u>Sortie Payloads</u>																					
	(Antenna Configurations Laser Technology, Traffic Management Techniques, Energy Transfer Experiment)										1	1	1	1	1	1	1	1	1	1	1	11

Note:

○ Approved and Ongoing

TABLE 13. PAYLOAD FLIGHT SCHEDULE FOR SPACE PROCESSING PROGRAM (SP)

[illegible]

TABLE 14. PAYLOAD FLIGHT SCHEDULE FOR SPACE TECHNOLOGY PROGRAM (ST)

[illegible]

TABLE 15. PAYLOAD FLIGHT SCHEDULE FOR
NON-NASA/NON-DOD PAYLOADS (NN/D)

Payload Code	Payload	CY	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	Total
	<u>Comm/Nav</u>																					
NN/D-1	International Comm.		3	1	2	1	1	1	2	3			2	3	2	2			2	3	2	30
NN/D-2	U.S. Domestic			7	3	1	1	4	1	1	2	2	4	1	1	2	2	6	2	2	1	43
NN/D-3	Disaster Warning										1	1			1					1		4
NN/D-4	Traffic Management					2	1	3	1	2	2	1	1	1		1		1		1		17
NN/D-5	Foreign Comm.		2	1	3	2	3	1			1	1	1	1	1	1	1	1	1	1	1	23
NN/D-6	Communication R&D/Prototype														1			1		1		3
	<u>Earth Observations</u>																					
NN/D-7	Tiros Operational Sat.		1	1	1	1	1	1	1													7
NN/D-8	Environ. Monitoring Sat.									1	1	1			1	1	1	1		1	1	9
NN/D-9	Foreign Syn. Met. Sat. (2 Systems)							1			1	1		1		1		1		1		7
NN/D-10	Geosyn. Oper. Environmental Sat.				1	1	1	1	1		1	1	1		1		1	1	1		1	13
	<u>Earth Resources Sat.</u>																					
NN/D-11	Low Earth Orbit (2 Systems)						1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
NN/D-12	Geosynchronous																	2		2		4
NN/D-13	Foreign Syn. Earth Obs. Sat.																	1	2		1	4
	<u>Earth and Ocean Physics</u>																					
NN/D-14	Global Earth & Ocean Monit. Sys.															3		3		3		9
	Total Autom.		6	10	10	8	9	13	7	8	10	9	10	8	9	12	6	19	9	17	8	188
	<u>Sortie Payloads</u>																					
NN/D-15	Space Manufacturing														1	2	1	2	1	2	1	10
NN/D-16	Foreign Sortie									2	3	3	4	3	4	3	4	3	4	3	4	40

IV. THE SHUTTLE SORTIE PROGRAM

The Shuttle Sortie Program, called the "Spacelab Program," is summarized in this section. This 1973 version is designed to complement the automated, free-flying spacecraft programs in the science and applications areas. By utilizing the features of the new Space Transportation System, the Spacelab program provides low-cost sensor and experiment development before committing those systems to the automated spacecraft mode for long duration operation. Direct manned involvement in other Spacelab science and applications utilizes man where he can contribute most effectively, as demonstrated in the recent Skylab program.

The sortie schedules presented in the preceding section are translated into specific science and applications payloads in this section. The three accommodation modes, (Fig. 1), are examples of the Spacelab configurations consistent with Shuttle capability. In all, there are 336 sortie missions constituting 34 percent of the 1973 Payload Model. Eighty-five percent are NASA missions, 3 percent are U.S. commercial missions, and 12 percent are foreign missions which break down by discipline as follows:

	<u>Percent</u>
NASA	
Space Physics and Astronomy	33
Earth Resources & Applications	30
Life Sciences	8
Space Technology	14
U.S. Space Manufacturing	3
Foreign Astronomy	3
Foreign Applications	4
Foreign General Science	<u>5</u>
	100

The three accommodation modes break down as follows:

	<u>Percent</u>
Pressurized Lab Only	8
Pressurized Lab and Pallet	53
Pallet Only	<u>39</u>
	100

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The following charts reflect the contents for each participating organization as well as the accommodation mode within the constraints of the Shuttle and Spacelab Systems. The material is organized by major discipline with specific mission areas illustrated in greater detail. Table 16 addresses the physics and astronomy sorties with Figures 2 through 5 showing examples of typical individual sortie flight arrangements. Applications sorties are similarly presented in Table 17 and Figures 6 through 8 with space technology and life sciences shown in Tables 18 and 19 and Figures 9 and 10.

The U. S. commercial and foreign sortie content (Table 20) is derived by analogy and extrapolation from NASA activity but coordinated with non-NASA and ESRO personnel.

Table 21 is a summary of the sortie payloads in terms of lab, lab and pallet, and pallet-only missions for NASA and non-NASA payloads. Table 22 is a further breakdown of sortie payloads for 7- and 30-day missions for each NASA discipline.

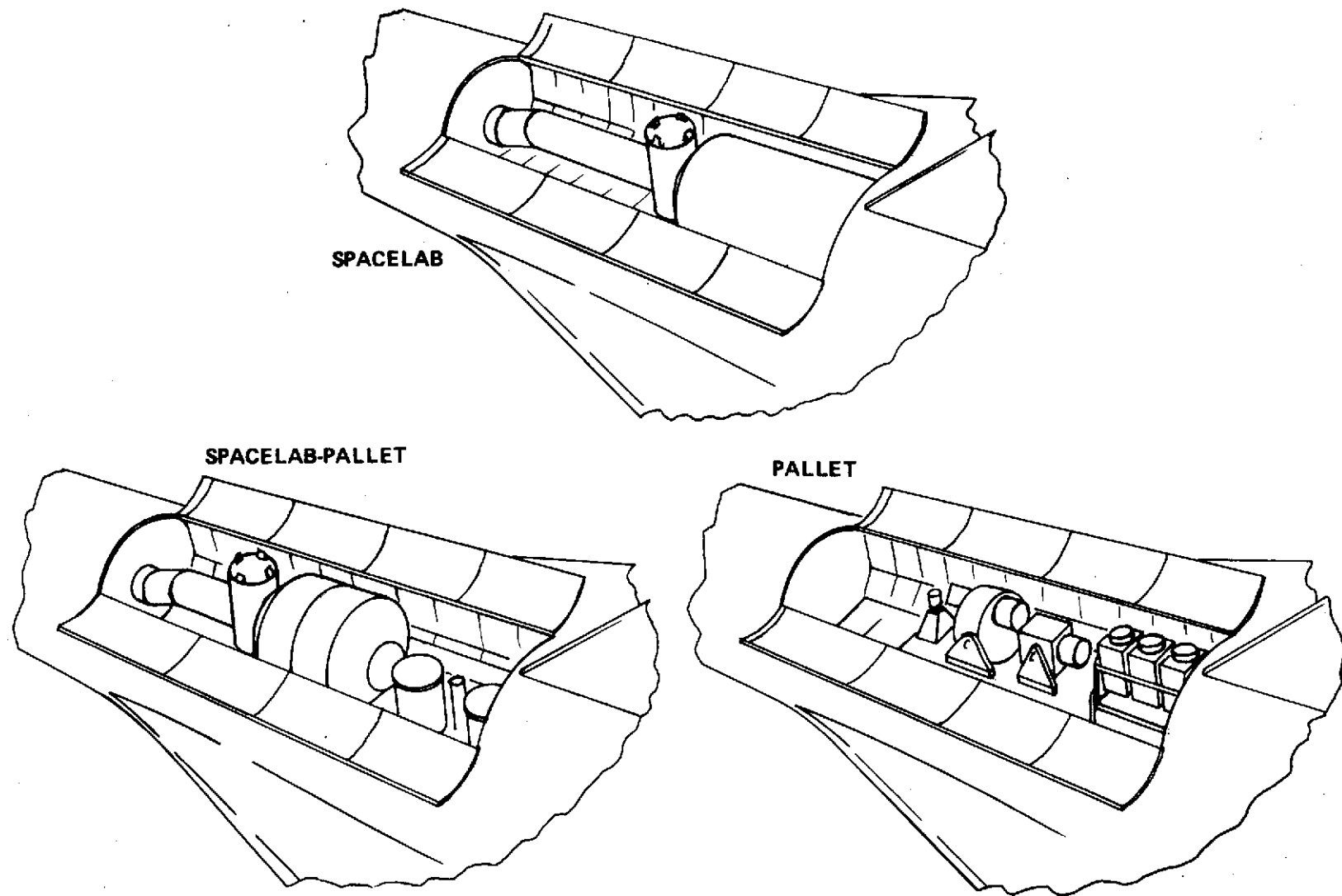


Figure 1. Shuttle/Spacelab operating modes.

TABLE 16. SORTIE MISSIONS, OFFICE OF SPACE SCIENCE

Discipline	Accommodation Mode	Payload Designation	Total Payloads			Average Experiment Per Year
			7-Day	30-Day	Total	
Astronomy	Pallet Only	Stellar Astronomy Package (IR, LH ₂ Telescope IR 4-m Telescope UV 1-m Telescope UV Sky Survey Package XUV Telescope)	23	10	33	30-35
Solar Physics	Pallet Only	Solar Physics Pallet Package (Photoheliograph, Coronagraph, etc.)	19	6	25	20-25
High Energy Astrophysics	Pallet Only	Cosmic, Gamma Ray, and X-Ray Package	16	6	22	8-10
Space Physics	Lab and Pallet	Plasma/Atmospheric Science Facility	30		30	30-40

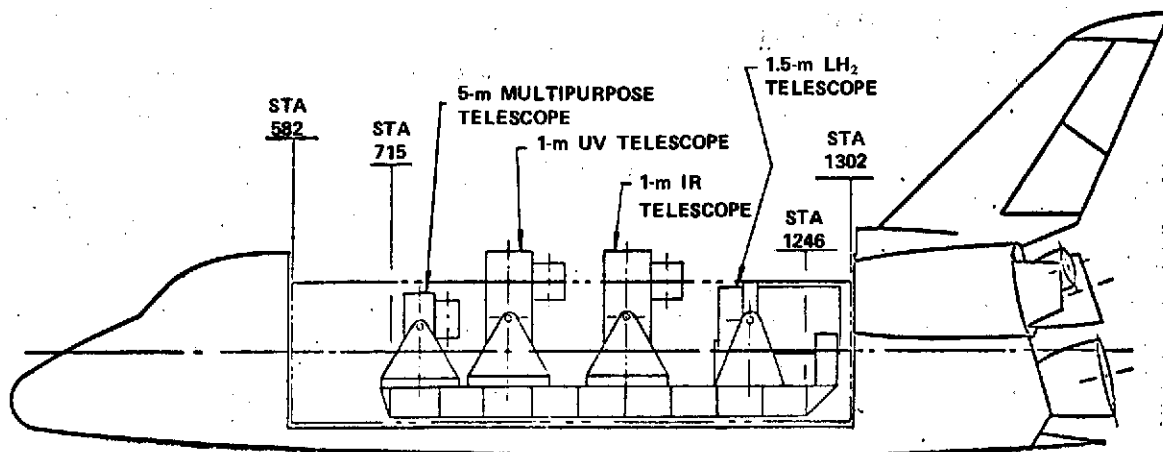


Figure 2. Stellar astronomy (pallet only).

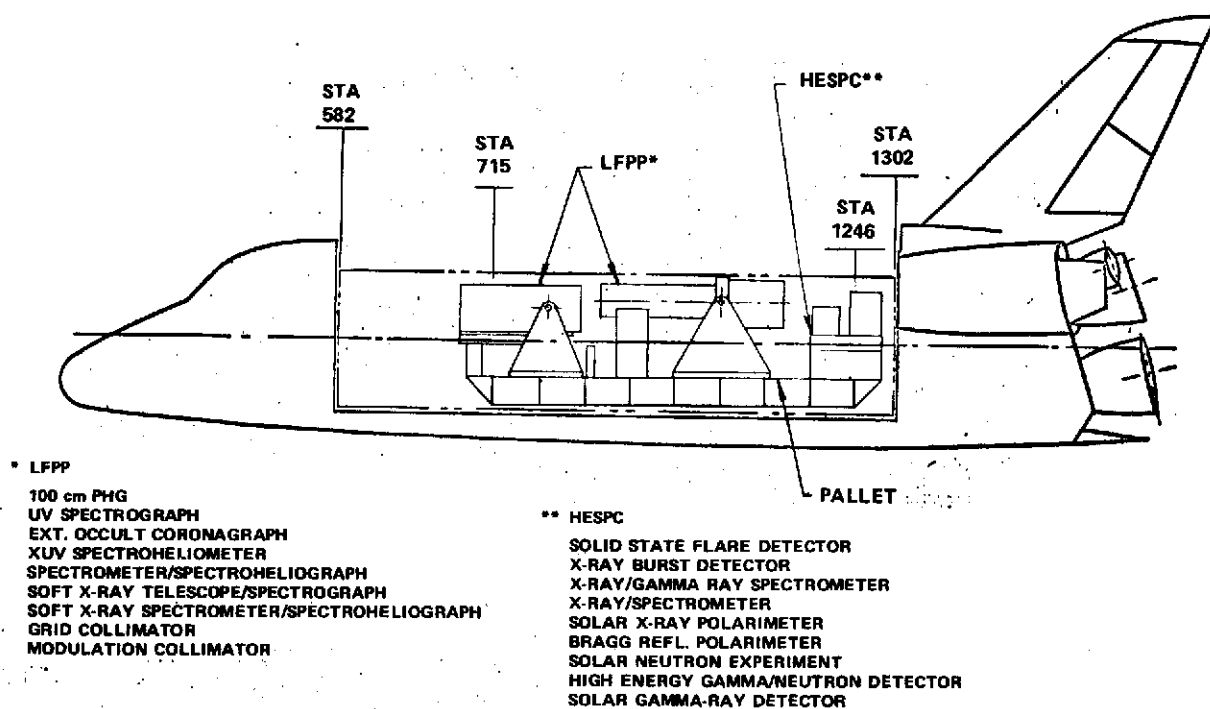


Figure 3. Solar physics (pallet only).

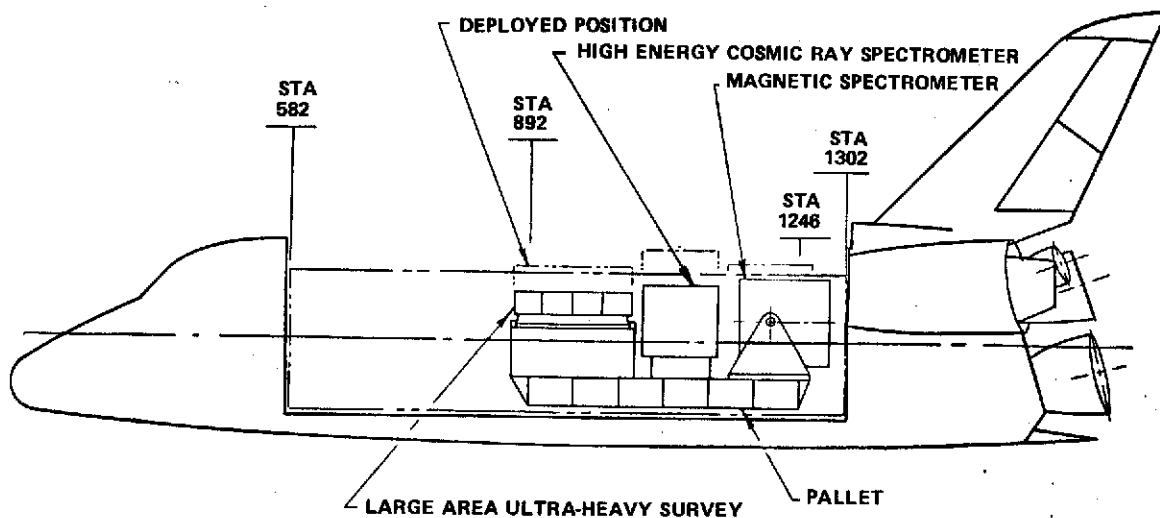


Figure 4. High energy astrophysics (pallet only).

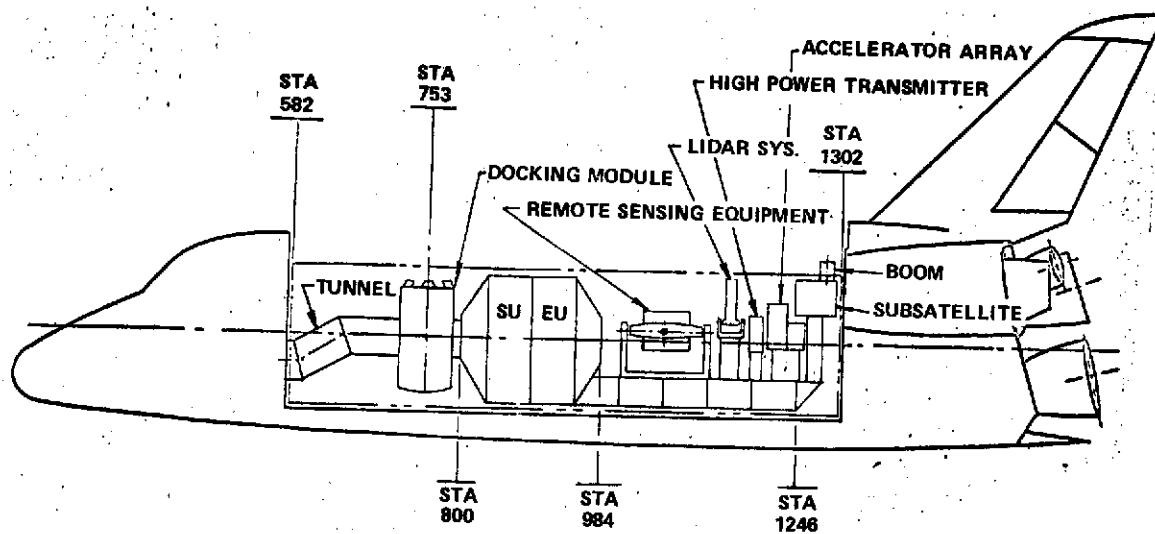
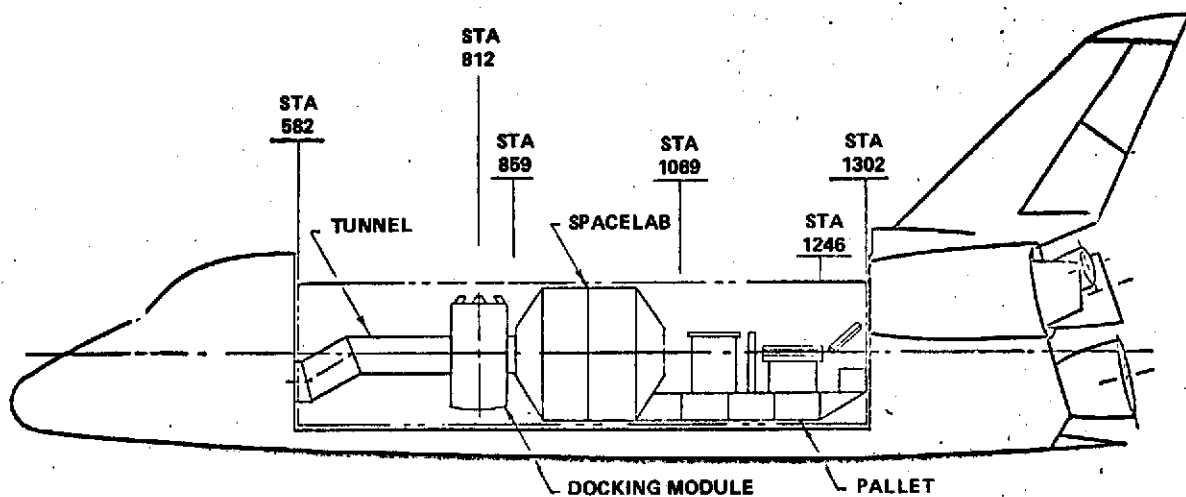


Figure 5. Atmospheric and space plasma physics (lab plus pallet).

TABLE 17. SORTIE MISSIONS, OFFICE OF APPLICATIONS

Discipline	Accommodation Mode	Payload Designation	Payloads (7 Days)	Average Experiment Per Year
Earth Observations	General Purpose Lab (GPL) Plus Pallet	Weather Simulation Studies	12	3-4
	GPL Plus Pallet	Remote Sensing Instruments Development (Scatterometer, Multispectral Scanner, etc.)	12	4-5
Earth/Ocean Physics	GPL Plus Pallet	Earth and Ocean Dynamics Sensor R&D	24	20-25
Communications and Navigation	GPL Plus Pallet	Comm/Nav Instrument R&D	11	25-30
Space Processing	Lab Plus Pallet	Materials/Manufacturing Research Facility (Furnace, Levitation Unit, etc.)	43	300-400



EXPERIMENT

- COMMUNICATIONS/NAVIGATION
- ZERO-G CLOUD PHYSICS
- EARTH AND OCEAN PHYSICS

Figure 6. Office of Applications general purpose laboratory no. 1.

EXPERIMENTS

- EARTH & OCEAN PHYSICS
- EARTH OBSERVATION

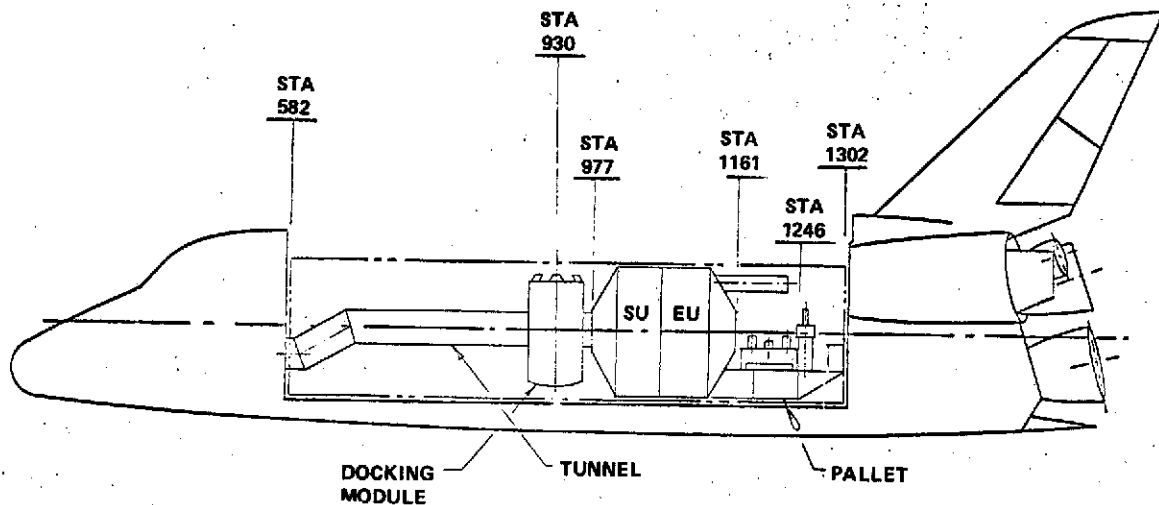


Figure 7. Office of Applications sortie general purpose laboratory no. 2.

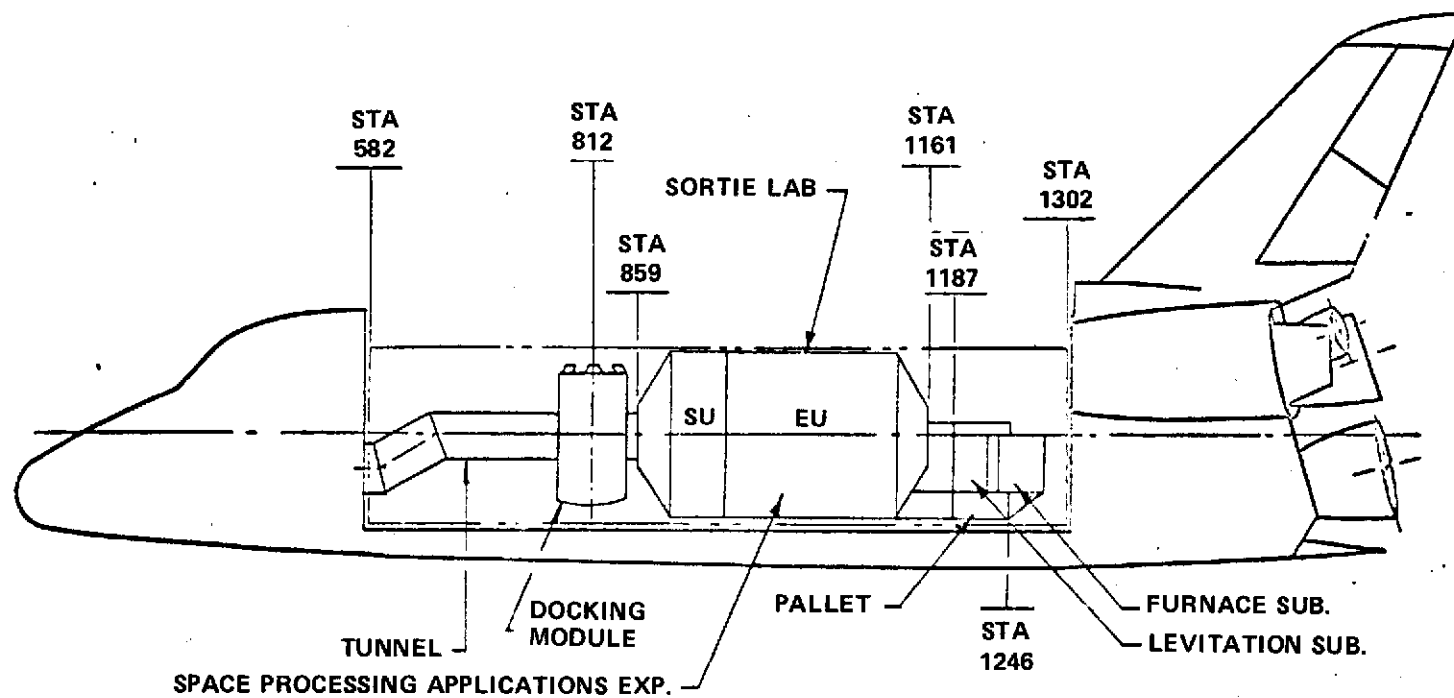


Figure 8. Space processing biology, furnace and levitation.

TABLE 18. SORTIE MISSIONS, OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY

Discipline	Accommodation Mode	Payload Designation	Total Payloads			Average Experiment Per Year
			7-Day	30-Day	Total	
Space Technology	Lab Plus Pallet	Advanced Research and Technology Facility (Fluid Physics, Gas Chemistry, Contamination Monitoring)	46		46	90-120

TABLE 19. SORTIE MISSIONS, OFFICE OF MANNED SPACE FLIGHT

Discipline	Accommodation Mode	Payload Designation	Total Payloads			Average Experiment Per Year
			7-Day	30-Day	Total	
Life Sciences	Lab	Life Sciences Research Lab (Bioengineering, Space Medicine, Bioresearch, etc.)	6	22	28	35-40

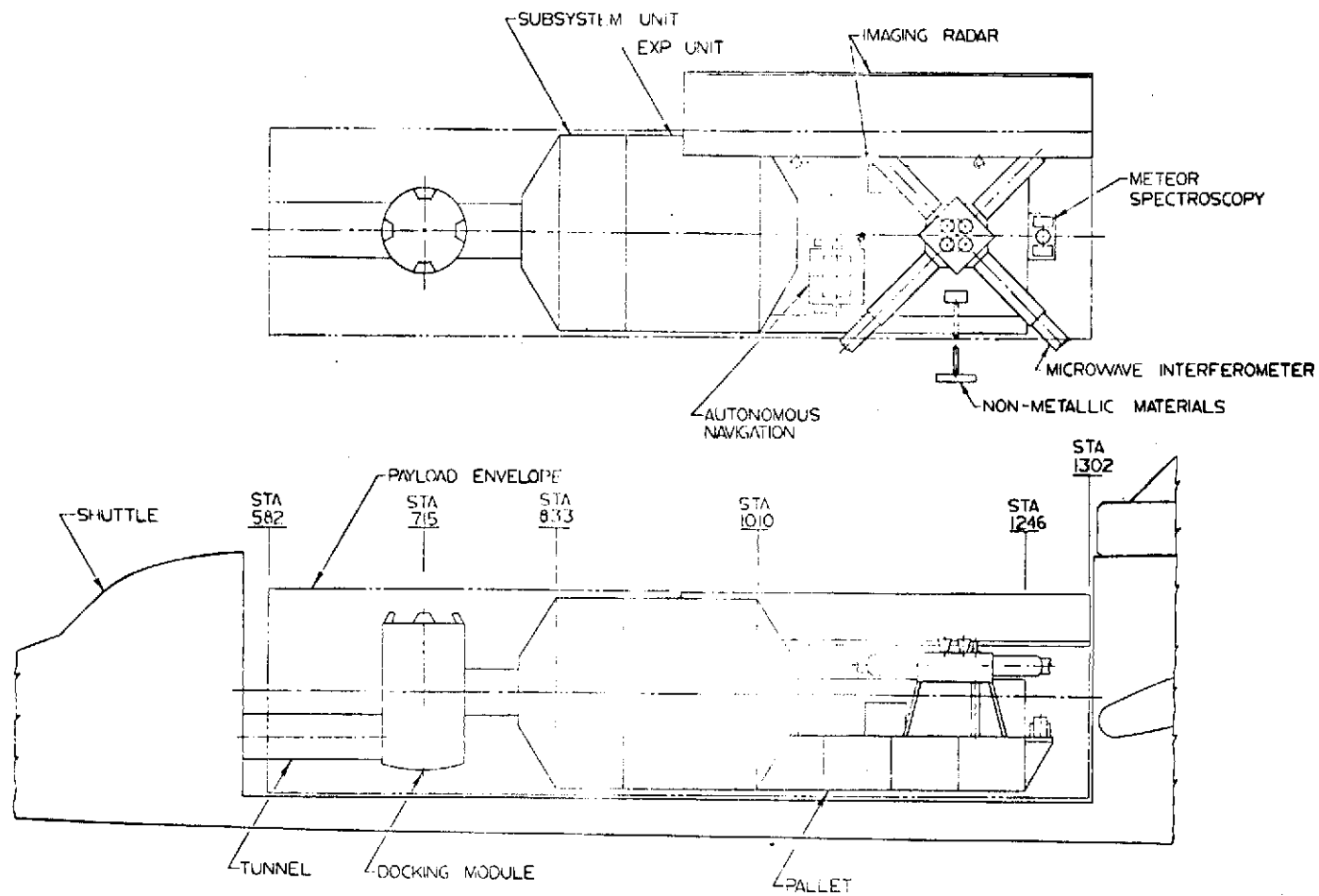


Figure 9. Space technology lab.

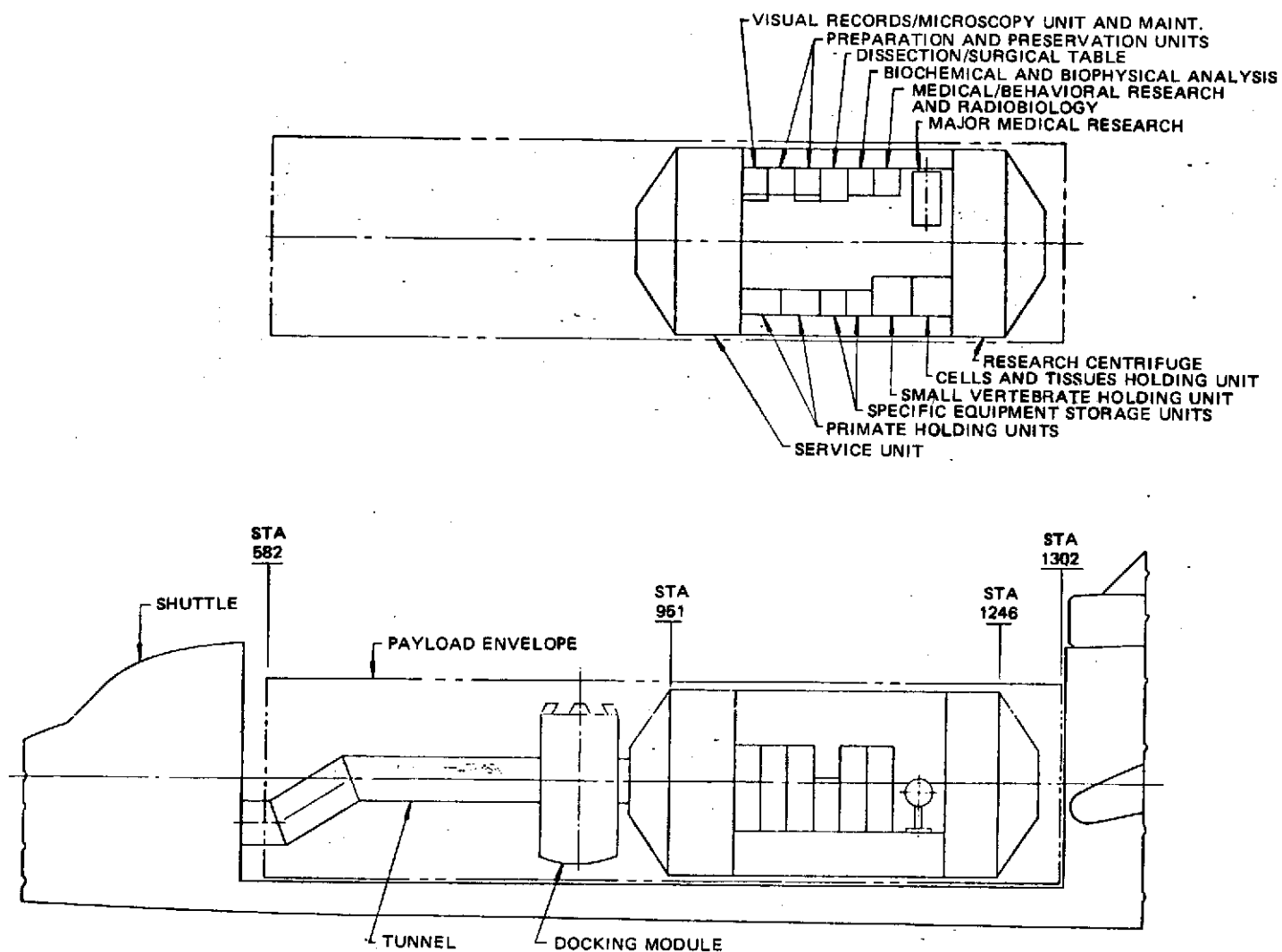


Figure 10. Life science laboratory.

TABLE 20. SORTIE MISSION, NON-NASA/NON-DOD SORTIE PAYLOADS

Discipline	Accommodation Mode	Payload Description	Payloads (7 Days)	Average Experiment Per Year
Space Manufacturing	Pallet Only	Materials/Manufacturing Facility	10	75-100
Foreign Astronomy	Pallet Only	Stellar Astronomy Packages (UV Telescopes, IR Telescopes)	11	10-13
Foreign Earth Observations	Lab Plus Pallet	Remote Sensing Instrument Development (Multifrequency Radiometer, Vertical Temperature, Profile Radar, etc.)	12	15-20
Foreign General Purpose Laboratory	Lab Plus Pallet	Multidiscipline Payloads Including Life Sciences, Solar Physics, High Energy Astrophysics, Technology, etc.	17	30-40

TABLE 21. TOTAL SORTIE PAYLOADS NASA AND NON-NASA

Discipline	Summary Missions	Lab	Lab and Pallet	Pallet
NASA				
OSS	110	0	30	80
OA	102	0	71	31
OMSF	28	28	0	0
OAST	<u>46</u>	<u>0</u>	<u>46</u>	<u>0</u>
Subtotal	286	28	147	111
Non-NASA/Non-DoD Space Processing	10		0	10
Foreign Sorties	40	0	29	11
Total	336	28	176	132

TABLE 22. NASA SORTIE PAYLOAD SUMMARY

Office	7-Day Missions	30-Day Missions
OSS		
Astronomy	23	10
Solar Physics	19	6
High Energy Astrophysics	16	6
Space Physics	<u>30</u>	<u>0</u>
Subtotal	88	22
OA		
Earth Observations	24	0
Space Processing	43	0
EOPAP	24	0
Comm/Nav	<u>11</u>	<u>0</u>
Subtotal	102	0
OAST		
Space Technology	46	0
OMSF		
Life Sciences	6	22
Total	242	44

V. SORTIE EQUIVALENT PROGRAM

To provide a basis for comparison between the Shuttle and expendable cases, it was necessary to develop an expendable launch vehicle program that would be equivalent to that provided by the Shuttle sortie missions. To achieve this equivalent program, two accommodation modes were assumed as illustrated in Figure 11.

Generally, those programs requiring manned participation are conducted on a space station with the unmanned ones conducted by automated spacecraft in orbit, on sounding rockets, or with balloons.

Since the Shuttle offers unique opportunities, it should be recognized that the so-called "equivalent" program could not truly be equal to the sortie program. The ability of the Spacelab to fly many instruments for short durations and to tailor each mission to a specific objective had to be traded off with flying fewer instruments for longer periods of time with less flexibility for tailoring a mission.

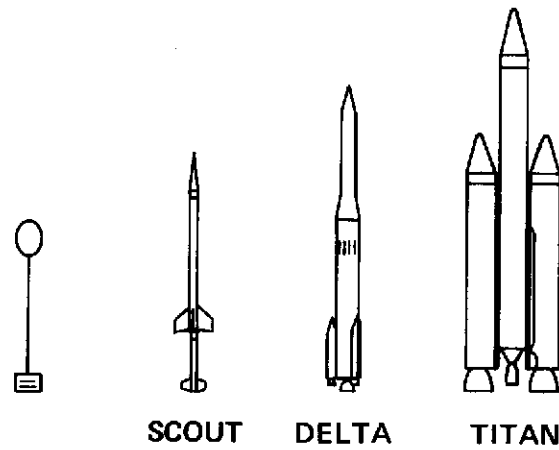
The sortie payloads within each discipline were examined and automated equivalents were developed. The objective of the automated equivalents is to achieve results comparable, to the extent practical, to their Shuttle sortie counterparts. In some cases, the automated program flew only a part of the instrument combinations that are included in the Shuttle sortie model; however, the instruments that were flown had longer on-orbit observation time. The rationale used for constructing the sortie equivalent program is given below:

1. Sortie missions configured to the expendable launch vehicle mode were selected based on the most effective approach to accomplish the same scientific objectives as the sortie missions.
2. Manned space stations are used only where cost effective or where man support is required.
3. Space station equivalent costs used NASA space station study results as a reference base.

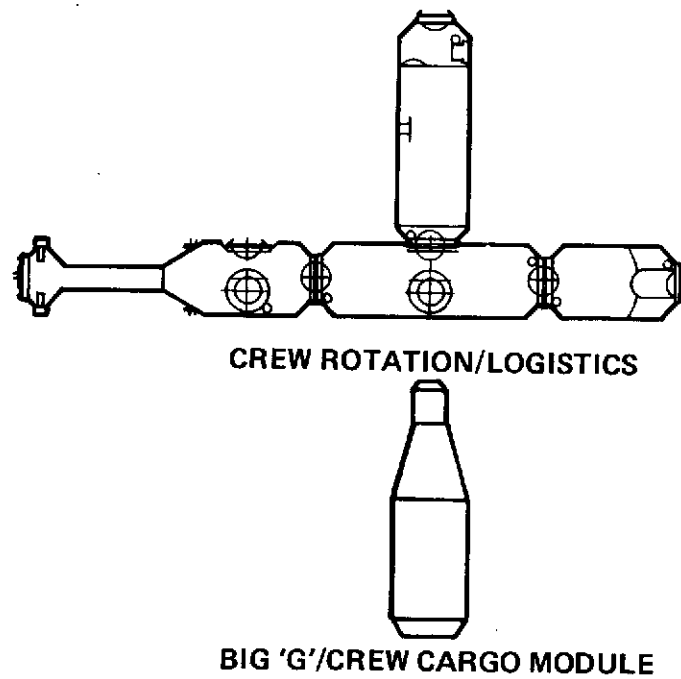
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4. Space station equivalent assumptions include the following:
 - a. Research and Application Module (RAM) and sortie lab experiment concepts are kept similar.
 - b. A "hot" mockup is used for ground verification of equipment to be installed in orbit.
 - c. RAM lab replaced in 6 years.
 - d. Increased experiment costs to account for:
 - (1) Increased reliability.
 - (2) Added testing and quality assurance.
 - e. Space station experiment facility will go through all-up environment testing.
5. Balloon and sounding rocket costs based on present programs.
6. Foreign sortie equivalent missions configured like similar NASA sortie equivalent missions.

The distribution of sortie payloads converted to automated and space station programs is given in Table 23. Tables 24, 25, and 26 specify the equivalent accommodation by discipline. In Table 27, the Space Station program providing experiment times equivalent to the Shuttle Spacelab is hypothesized.



a. Balloons/sounding rockets/automated spacecraft.



b. Minimal space station (3-man operation).

Figure 11. Sortie equivalent potential modes for mission accomplishment.

TABLE 23. SORTIE MISSIONS CONVERTED TO EQUIVALENT MODE

	Automated (%)	Space Station (%)
OSS	100	0
OA	46	54
OAST	0	100
OMSF	0	100
Foreign	85	15
Non-NASA Space Processing	0	100

TABLE 24. SORTIE EQUIVALENT SPACE STATION OPERATIONS

INITIAL OPERATIONS	3 CORE MODULES POWER CREW GENERAL PURPOSE LAB	TITAN LAUNCHED
RAM PLACEMENT	RAM FULLY SUPPLIED INITIALLY	TITAN LAUNCHED
CREW ROTATION	BIG G/CCM (5 FLIGHTS PER S/C)	TITAN LAUNCHED

SCHEDULE

	80	81	82	83	84	85	86	87	88	89	90	91
STATION MODULES	3											
RAMS	3						3					
CREW ROTATION	2	4	4	4	4	4	4	4	4	4	4	4
LOGISTICS		1	1	1	1	1	1	1	1	1	1	1

TABLE 25. ASSUMED SORTIE EQUIVALENT APPROACH (AUTOMATED SPACECRAFT)

Discipline	P/L	Sortie Program	P/L	Sortie Equivalent ^a	Rationale
Astronomy	33	Stellar Astronomy Pallet (NASA)	375	Sounding Rockets	<ul style="list-style-type: none"> • Flexibility in Inclination • Quick Turnaround, Frequent Flight Opportunity • Use of Low Cost Off-The-Shelf Hardware • Opportunity for Easy Variation in Sensor Complement and Arrangement
	11	Stellar Astronomy Pallet (Foreign)	36	Automated Spacecraft (LST and OAO Type)	
Solar Physics	40	Solar Physics Pallet (NASA)	470	Sounding Rockets	
	2	Solar Physics GPL (Foreign)	48	Balloons	
			7	Automated Spacecraft (OSO Class)	
High Energy Astrophysics	37	Cosmic, Gamma and X-Ray Pallets (NASA)	720	Balloons	
	1	High Energy Experiments (Foreign)	5	Automated Spacecraft (HEAO Class)	
Space Physics	30	Atmospheric and Space Physics Lab (NASA)	128	Sounding Rockets	
	2	Space Physics (Foreign)	18	Automated Spacecraft (Physics Obs. Class)	
Earth and Ocean Physics	12	Earth and Ocean Dynamics, GPL Plus Pallet (NASA)	12	GEOS and SEASAT Class Spacecraft	<ul style="list-style-type: none"> • Flexibility of Inclination and Altitude • Require High Inclination Orbits
Comm/Nav	11	C&N GPL Plus Pallet (NASA)	18	INTELSAT Class (Low Orbit)	
	6	C&N GPL (Foreign)			
Earth Observations	12	R&D Platform GPL Plus Pallet (NASA)	12	EOS Class Spacecraft	
	12	R&D Sensor Development Lab (Foreign)	6	EOS Class	

a. Equivalent flights for NASA and foreign are in direct ratio to the sortie missions.

TABLE 26. ASSUMED SORTIE EQUIVALENT APPROACH (SPACE STATION)

Discipline	P/L	Sortie Program	Sortie Equivalent	Rationale
Earth Applications Observations	12	Cloud Physics Lab (NASA)	RAM/Space Station Lab	<ul style="list-style-type: none"> ● Manned Attendance Essential ● Fixed Facility
Material Processing	43 10 3	Material Processing Lab/Pallet (NASA) Space Manufacturing (Non-NASA) Space Processing (Foreign)		<ul style="list-style-type: none"> ● Manned Support Desirable ● Large Sample Return Requirement
Life Sciences	28 2	Bioscience Lab (NASA) Bioscience Group (Foreign)	RAM/Space Station Lab	<ul style="list-style-type: none"> ● Manned Support Essential ● Large Sample Return Requirement
Advanced Technology	46 1	Advanced Technology Lab (NASA) Technology (Foreign)	RAM/Space Station Lab	<ul style="list-style-type: none"> ● Crew Obs. Anal. and Adjustment are Essential Functions in Operation

TABLE 27. SORTIE EQUIVALENT, SPACE STATION EQUIVALENT,
DEDICATED RAM PAYLOADS

Discipline	Maximum Sortie Requirement	Space Station Operation ^a (days/yr)	Logistics Support per Year ^b (lb)
Applications			
Space Processing (NASA and Non-NASA)	6/yr - 7 days	40	8000
Space Processing (Foreign)	1/yr - 7 days		1000
Earth Observations (NASA)	1/yr - 7 days		500
Space Technology (NASA)	4/yr - 7 days	25	7500
Space Technology (Foreign)	0.5/yr - 7 days		700
Life Sciences (NASA)	3/yr - 30 days	100	9000
Life Sciences (Foreign)	0.5/yr - 7 days		1500

a. Requires 160 days/yr for setup/calibration.

b. Station resupply per year - 22 000 lb.

VI. PAYLOAD DATA PREPARATION

The methodology used in preparing the payloads for use in the capture analysis is discussed in this section. This includes both the automated and sortie payloads.

A. Automated Payloads

The automated payload weight and dimensional data, as obtained from the various Program Office sources and as shown in Payload Model, generally represent current design practice for expendable payloads. A large fraction of the costs inherent in current payload designs can be attributed to the necessity of minimizing weight and volume while simultaneously maximizing spacecraft reliability. The Shuttle provides the capability to retrieve and reuse payloads and also alleviates previous constraints on the weight, volume, and number of payloads per flight. To determine the effect of fully utilizing the Shuttle capabilities, each payload is analyzed to determine a weight and a dimension corresponding to a change in design practice in order to take advantage of the ability to reuse the payload and/or to reduce the cost by relaxing size and weight constraints. This is accomplished by using low-cost payload sizing techniques to resize the spacecraft and subsystems for each payload.

The low-cost payload sizing approach (assimilated in a computer program) develops subsystem weight and total spacecraft size characteristics for four payload design classes — CE, CR, LCE, and LCR. The four classes of payloads are defined as follows:

Current Expendable (CE) — A current unmanned payload designed for launch on an expendable launch vehicle.

Current Reusable (CR) — A current expendable payload design that has been modified for Shuttle deployment and a weight adjustment for docking and retrieval capability.

Low Cost Expendable (LCE) — An expendable payload design for launch by the Space Shuttle or Shuttle/Tug without the traditional costly constraints on weight and volume.

Low Cost Reusable (LCR) — An LCE payload design plus modifications for Shuttle rendezvous, retrieval, and refurbishment.

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The payload sizing technique was developed initially by The Aerospace Corporation utilizing design data/trends from the Lockheed Missiles and Space Company low-cost payload studies. This program was subsequently refined by MSFC to include modifications such as the structure versus equipment weight curve to include Applications Technology Satellite H&I data points. Payload sizing factors were derived from the previous five Lockheed Missiles and Space Company spacecraft designs [Small Research Satellite (SRS), Orbiting Astronomical Observatory (OAO), Synchronous Earth Observation (SEO), Earth Observatory Satellite (EOS), and COMSAT] for application at the sub-systems level. The Payload Sizing Program methodology is presented in Figure 12.

Because the program was written to start from a reference design (in this case, current expendable) and develop, through weight factors and sizing relationships, the characteristics of the CR, LCE, and LCR payloads, it was necessary to identify a CE design for all payloads in the Payload Model. Therefore, the payload system requirements and characteristics were obtained from the Payload Program Offices and SSPD data and a determination was made relative to its payload class (i. e., CE, LCR, etc.). Subsystem weights for the CE designs were then used as the basis for developing the CR, LCE, and LCR designs. Payload characteristics were developed for some 60 automated payloads.

B. Sortie Payloads

Forty-five sortie payloads were defined for the capture analysis. Data developed included design layouts, weight, and center of gravity locations. Sortie payloads were constrained to the 32K lb down payload restriction of the Shuttle and current two percent c. g. envelope. Weight statements were prepared for launch, abort, and return conditions for each payload. A docking module was included in all sortie missions which had a pressurized Spacelab. Several of the sortie configurations were presented in Section III.

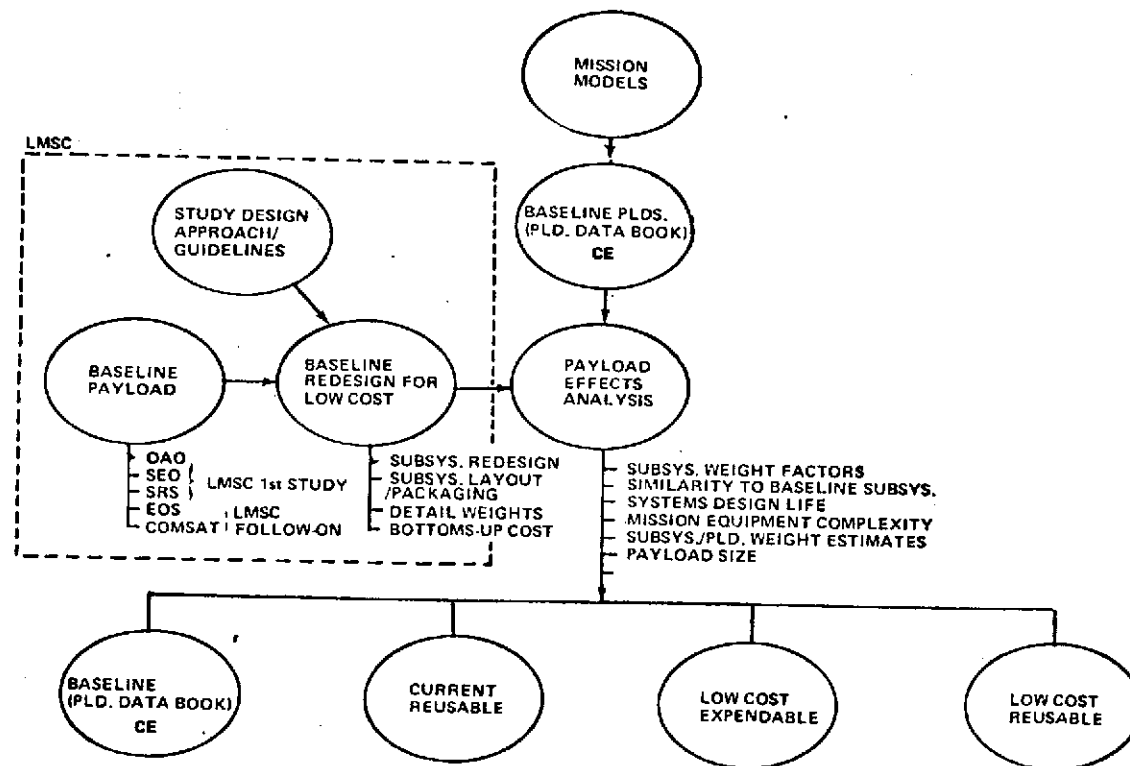


Figure 12. Payload effects application.

VII. CAPTURE ANALYSIS

The capture analysis is an evaluation of the number of missions and the associated flight schedules required to support the Payload Model. This analysis is conducted in two major parts: The first one determines the number of flights and the schedules using the Shuttle and Shuttle plus Tug as the launch system; the second uses candidate expendable launch vehicles. The starting point for all capture analysis work is the Payload Model which defines the kind and number of payloads to be launched in each calendar year, classified by supplier or source organization and the mission objective. Associated information required for each payload includes the desired orbit (and energy for escape missions), mission duration, number and timing of revisits if required, and the physical characteristics. From this starting point, various detailed operations analyses are performed on the data to extract the results, presented in the Shuttle and Expendable Launch Vehicle documents of References 5 and 6.

A. Shuttle/Tug Capture Analysis

The Shuttle/Tug capture analysis begins with a preliminary step in which the required year for launch of each payload and the mean mission duration are used to determine which payloads should be retrieved and when retrieval can occur. In turn, it is determined which payloads may be refurbished for subsequent launch and which must be new items. The results of this step are a launch schedule for new payloads, a launch schedule for refurbished payloads, and a payload retrieval schedule.

Using these schedules and taking each calendar year in turn, the payloads are arranged in order of descending energy requirements for flight assignment. This ordered list forms several groups representing the flight hardware units or procedures necessary to accomplish the mission, i. e., tandem Tug flights, orbital docking of a payload and Tug launched separately, Tug, or one or more Shuttle Orbital Maneuvering System (OMS) propulsion kits.

The first (highest energy requirement) payload on the list is selected and assigned to a Shuttle, and the necessary additional propulsion is assigned in terms of Tugs or OMS kits. If any additional capability remains, the list is scanned and additional payloads are assigned to this flight until remaining capability is smaller than any remaining energy requirement, thus completing the payload assignments for this Shuttle flight.

By this technique, the highest energy payload is selected from the list of remaining unscheduled payloads and the process is repeated for another Shuttle flight. This procedure is repeated until all payloads for a given year have been assigned to a Shuttle flight, along with the required Tug stages and OMS kits. If payload retrievals are required in the year being analyzed, they are assigned to flights in a manner similar to the launch scheduling, utilizing delivery flights for retrieval when possible. The algorithm then shifts to the next year and the whole process is repeated to completion.

In determining the most appropriate payload configuration ("best mix") to use from among the four payload design types (CE, CR, LCE, and LCR), the steps described above are conducted four times, one for each type of payload. (Certain obvious exceptions occur; for example, planetary and lunar payload missions utilize only the expendable type payloads.) The cost is then determined for each of these launch and retrieval schedules. The payload type which results in the minimum program cost (payload plus transportation) for each payload is retained. The capture analysis process is then used once more to obtain the payload assignments and flight schedules for a minimum cost, or "best mix," of payload types.

Certain other constraints are used in the analysis which must all be applied simultaneously. Payloads, Tug stages, and OMS kits are assigned to a Shuttle flight under the additional requirements that the Shuttle center of gravity is maintained within prescribed limits, that the Shuttle maximum landing weight is not exceeded, and that the combined length of these units does not exceed 60 feet (the cargo bay length). Another potential limitation is the number of Shuttle vehicles available at program initiation. Therefore, the accomplishment of the payload program requires the use of some expendable launch vehicles in the early years until the Shuttle is fully operational.

B. Expendable Launch Vehicle Capture Analysis

This part of the analysis utilizes a set of 19 candidate launch vehicles selected for availability, ability to span the required payload weight range, and ability to perform the required mission sequence. The set is composed of Scout, variations of the Delta vehicle, and the Titan family of launch vehicles using Agena, Centaur, and Burner II upper stages in various combinations. The set is arranged in order of preference, the most preferable being the least costly. Taking each calendar year in turn and beginning with the heaviest payload to be launched, the least costly launch vehicle capable of performing the mission is selected. The remaining payloads are then scanned to determine

if there are any requiring the same orbit which can also be launched on this vehicle to utilize any unused performance capability; if so, they are scheduled. The process is repeated using the next heaviest payload until all are matched to a launch vehicle. An additional assumption used in the analysis is that each payload must be launched on the same vehicle initially used.

The capture analysis is repeated using current expendable payload types in the first case and low cost expendable types in the second case. The cost for each launch is then determined and the case yielding the least expensive program cost (payload and transportation) is retained. This constitutes the "best mix," or least costly, set which will accomplish the payload program.

C. Reliability Effects

The abort flights are based on the reliability factors listed below:

Shuttle Flights

Payloads Only

6 percent Payload Abort
0.5 percent Shuttle Abort
 6.5 percent

Payloads Plus Tug

6 percent Payload Abort
 0.5 percent Shuttle Abort
 2 percent Tug
 1 percent Abort -- No Loss
1 percent Tug Loss
 8.5 percent

Expendable Launch Vehicle

Payloads Only

6 percent Payload Abort
3 percent Launch Vehicle Abort
 9 percent

The total aborts included abort flights on abort flights, i. e., the abort flights are subject to the same reliability impacts as the normally scheduled flights. All payloads, including sorties, are assumed to have a 6 percent failure. Payloads are lost during the years the interim Tug is used. All payloads launched on expendable launch vehicles are lost due to lack of recovery capability.

D. Flight Hardware Inventory

To determine the required number of flight articles for the Shuttle, Tug, and Spacelab modules, a simulation of the flight and ground operations sequence for the Space Transportation System and payloads was developed and exercised. Input data include the "best mix" Shuttle/Tug flight schedule, mission duration, and the time intervals involved in each step of the preparation of the hardware units for flight and for reuse after flight. The simulation depicts the status of each unit of each type at any time and allows the analyst to change the sequence start time for each unit and to add units until the required number and type of flight articles are calculated to be ready for launch at the required time.

E. Capture Analysis Results – Traffic Model

Shuttle/Tug Traffic — Results of the Shuttle/Tug capture analysis are indicated in Tables 28 through 31 and Figures 13 and 14.

The number of Shuttle and Tug flights required is shown in Table 28. Tug stages were required on 40 percent of the Shuttle flights.

The sortie missions are made up of 336 payloads (NASA and non-NASA sorties), as shown in Table 1, which required 276 Shuttle flights, as shown in Table 29. Pallets carrying sortie class payloads were flown on an additional 73 Shuttle flights whose primary purpose was automated payload deployment.

The results of the Shuttle/Tug capture analysis are summarized in Figures 13 and 14 in terms of various parameters which reflect the major payload and flight traffic characteristics.

There is a total 650 automated payloads, as shown in Table 2. Of these, 346 are NASA and non-NASA automated payloads, of which 203 are new payloads built from the ground up using, to the maximum extent possible, low-cost techniques such as commonality and modular construction, and 143 are refurbished and returned to operation by in-orbit servicing or return-to-earth refurbishment. Table 30 shows that 275 of the automated payloads are retrievable. Of these, 244 are launched as refurbished payloads. Sortie payloads, which remain attached to the Shuttle, comprise 34 percent of the total 986 payloads.

The payload types which comprise the "best mix," or lowest cost, programs are summarized in Table 31. For the expendable launch vehicle case, cost benefits result from applying low cost design techniques to 510 of the 821 payloads in the model. For the Shuttle case, benefits can be derived from designing 838, i.e., 85 percent, of the payloads for reusability.

The results of the Space Transportation System and payload operations simulation to determine the required number of Shuttle orbiters, Tugs, and Spacelab modules are shown in Table 32. Also shown is the required phasing of hardware procurement. The assumptions used to determine the flight hardware inventory are listed below:

Orbiters

1. Orbiters shared by NASA and DoD (five at ETR, two at WTR).
2. No exchange of orbiters between launch sites.
3. Ground turnaround time of 2 weeks.
4. Two launch pads at each launch site.
5. Each orbiter scheduled once for 90 consecutive days in the last 5 years of traffic model (1987-1991) for major inspection/overhaul.
6. Fourteen days per year per orbiter allowance for unscheduled repairs/modifications.
7. Three percent of flights will land at alternate site and require ferry flight involving 14 days of lost time.

Tugs

1. Separate Tug fleet established at WTR and ETR.
2. Only initial performance Tugs expended.
3. Kick stage used to minimize expending Tugs for planetary missions.
4. No additional Tug procurement due to wear out.

Spacelab

1. Common inventory of support modules used to accommodate Space-lab program.
2. Separate inventory of other Spacelab elements (experiment modules, pallets, bulkheads, etc.) assigned each discipline as required.
3. No additional Spacelab elements procured due to wear out except support module.

During the Shuttle build-up years (1980-1982), 80 expendable launch vehicle flights were required from both KSC and WTR. A summary of the use of these expendable launch vehicles is given in Table 33.

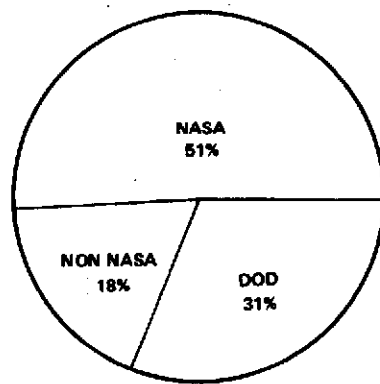
Expendable Launch Vehicle Traffic -- The results of the expendable launch vehicle analysis are given in Tables 34 and 35. The Titan family of launch vehicles in combination with various upper stages is used for 87 percent of the launches, the Delta family captures 11.5 percent, with Scout used for the remaining 1.5 percent.

TABLE 28. SHUTTLE AND TUG TRAFFIC SUMMARY

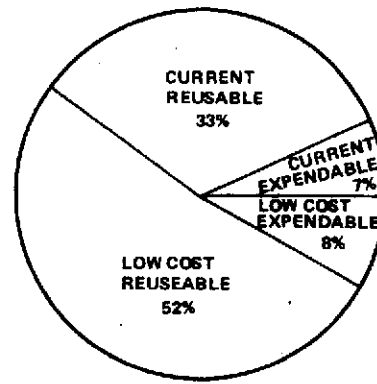
PROGRAM	YEAR												TOTAL
	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	
<u>NASA & NON-NASA</u>													
SHUTTLE FLIGHTS													
KSC	14	32	27	34	35	42	42	37	39	33	42	39	416
WTR			1	7	10	9	10	8	9	11	11	9	85
TOTAL	14	32	28	41	45	51	52	45	48	44	53	48	501
TUG FLIGHTS													
KSC		12	5	13	14	15	17	12	12	11	14	11	136
WTR					4	1	1	2	2	2	2	2	16
TOTAL		12	5	13	18	16	18	14	14	13	16	13	152
<u>DOD</u>													
SHUTTLE FLIGHTS													
KSC		2	9	11	15	6	9	10	11	6	13	8	100
WTR				16	13	17	12	14	11	15	11	15	124
TOTAL		2	9	27	28	23	21	24	22	21	24	23	224
TUG FLIGHTS													
KSC		2	9	11	15	6	9	10	11	6	13	6	98
WTR				6	4	5	4	4	3	5	3	5	39
TOTAL		2	9	17	19	11	13	14	14	11	16	11	137
SUBTOTAL													
SHUTTLE FLIGHTS	14	34	37	68	73	74	73	69	70	65	77	71	725
TUG FLIGHTS		14	14	30	37	27	31	28	28	24	32	24	289
ABORT FLIGHTS													
SHUTTLE		2	3	5	6	6	6	6	6	5	6	6	57
TUG		1	1	3	4	2	3	2	2	2	3	2	25
TOTAL													
SHUTTLE FLIGHTS	14	36	40	73	79	80	79	75	76	70	83	77	782
TUG FLIGHTS		15	15	33	41	29	34	30	30	26	35	26	314

TABLE 29. SORTIE FLIGHT SUMMARY

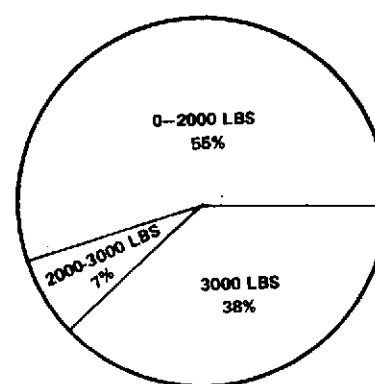
	Year												Total
	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	
NASA Sorties													
Lab	2	2	2	2	2	2	2	2	3	3	3	3	28
Pallet	2	4	6	7	8	11	10	9	9	9	8	9	92
Lab Plus Pallet	5	8	8	8	10	10	11	10	11	10	11	10	112
	9	14	16	17	20	23	23	21	23	22	22	22	232
Foreign Sorties													
Lab	0	0	0	0	0	0	0	0	0	0	0	0	0
Pallet	0	1	1	1	1	1	1	1	1	1	1	1	11
Lab Plus Pallet	2	2	2	3	2	3	2	3	2	3	2	3	29
	2	3	3	4	3	4	3	4	3	4	3	4	40
Non-NASA — U.S. Domestic Pallet									1	1	1	1	4
Total	11	17	19	21	23	27	26	25	27	27	26	27	276
Flight Sharing With Automated Payloads	0	4	5	10	7	8	9	5	7	6	6	6	73



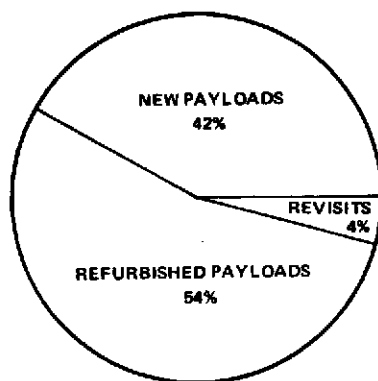
PAYLOADS DISTRIBUTION BY USER



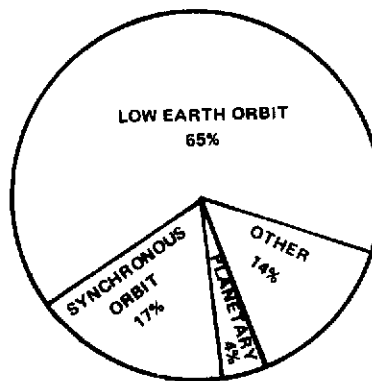
PAYLOAD DESIGN TYPE



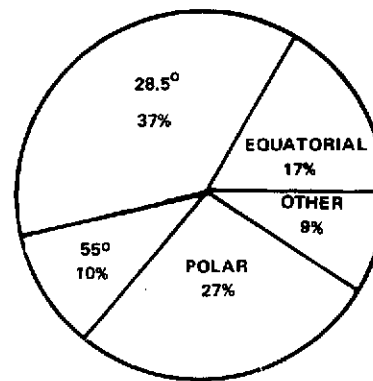
PAYLOAD WEIGHT CLASS
(ONLY SYNCH MISSIONS)



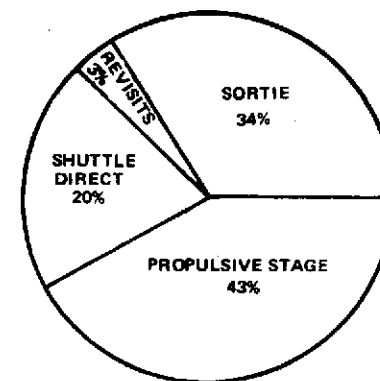
PAYLOAD REUSE



MISSION DESTINATION



ORBIT INCLINATION



MISSION MODE

Figure 13. 1973 best mix payload summary (986 payloads).

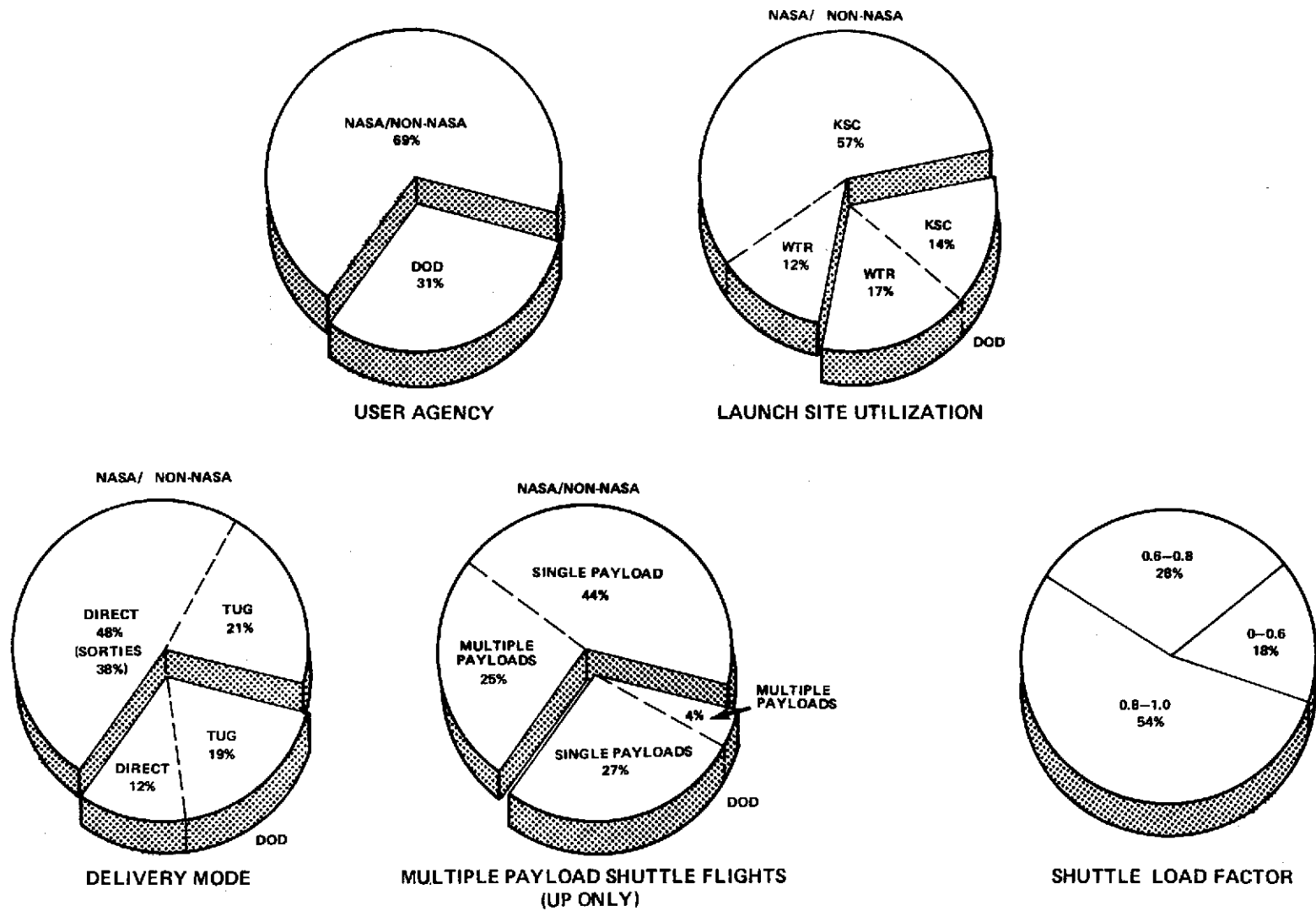


Figure 14. 1973 Shuttle traffic summary (725 flights).

**TABLE 30. SHUTTLE LAUNCHED PAYLOAD
TRAFFIC SUMMARY BEST MIX OF PAYLOADS NASA, NON-NASA & DOD**

MODE OF OPERATION	YEAR												TOTAL
	80	81	82	83	84	85	86	87	88	89	90	91	
SORTIES	13	20	24	26	28	32	33	31	33	32	32	32	336
REVISITS	0	1	2	1	5	4	2	6	4	6	7	6	44
LAUNCH NEW	4	20	19	49	22	28	26	21	25	17	18	18	267
LAUNCH REFURBISHED	3	3	5	7	26	22	30	25	30	29	39	25	244
LAUNCH NEW ON EXP. LAUNCH VEHICLES	52	26	17										95
TOTAL UP PAYLOAD TRAFFIC	72	70	67	83	81	86	91	83	92	84	96	81	986
RETRIEVALS	5	5	7	18	42	24	30	29	31	30	29	25	275

EXPENDABLE VEHICLE LAUNCHED PAYLOAD TRAFFIC SUMMARY

MODE OF OPERATION	YEAR												TOTAL
	80	81	82	83	84	85	86	87	88	89	90	91	
LAUNCH NEW	78	59	57	68	70	72	76	66	72	63	82	58	821

TABLE 31. PAYLOAD TYPE SUMMARY (BEST MIX)

SHUTTLE

PAYLOAD TYPE	NO. PAYLOADS LAUNCHED 1980-91			
	NASA	NON-NASA	DOD	TOTAL
CURRENT EXPENDABLE	14	—	51	65
CURRENT REUSABLE	92	72	164	328
LOW COST EXPENDABLE	60	19	4	83
LOW COST REUSABLE (INCLUDES SORTIES)	341	84	85	510
TOTAL	507	175	304	986

EXPENDABLE LAUNCH VEHICLE

PAYLOAD TYPE	NO. PAYLOADS LAUNCHED 1980-91			
	NASA	NON-NASA	DOD	TOTAL
CURRENT EXPENDABLE	108	83	120	311
LOW COST EXPENDABLE	255	72	183	510
TOTAL	363	155	303	821

TABLE 32. STS FLIGHT HARDWARE

ITEM	CY	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
ORBITERS ^a		1	1	2	2	1								7
TUGS														
INITIAL			5		5								1	12 ^b
FINAL						5								7 ^b
KICKSTAGE			2	1	2	2	2	1		1		2	3	16
SPACELAB/PALLETS (MODULARIZED)														
SUPPORT MODULES		2					1				2			5
TEN FT EXP MODS		3												3
SIX FT EXP MODS		4	1											5
AFT BULKHEADS		6	1											7
TEN FT PALLETS		17	10	2		1								30
FIVE FT PALLETS		7	4	2		1		1						15

a. BASED ON CURRENT PROCUREMENT PLANNING

b. TOTALS REFLECT 1% RISK EACH FLIGHT OF NOT RECOVERING TUG

TABLE 33. EXPENDABLE LAUNCH VEHICLE TRAFFIC SUMMARY,
ASSIGNED DUE TO WTR AVAILABILITY AND SHUTTLE BUILDUP RATE

EXPENDABLE LAUNCH VEHICLES	LAUNCH SITE	1980		1981		1982		TOTAL	
		NASA & NON-NASA	DOD	NASA & NON-NASA	DOD	NASA & NON-NASA	DOD	NASA & NON-NASA	DOD
SCOUT	KSC WTR	2 2						2 2	
DELTA 300	KSC WTR	1		3		1		5	
DELTA 600	KSC WTR	0		1		0		1	
DELTA 900	KSC WTR	1		0		1		2	
DELTA 904	KSC WTR	1		1		2		4	
TIIB/C	KSC WTR	1		1		1		3	
TIID7	KSC WTR	0		0		0		0	
TIID/C/BI	KSC WTR	1		0		0		1	
TIIB/A	KSC WTR	2		0		0		2	
TIIB/C/BI	KSC WTR								
TIID	KSC WTR	1 1						1 1	
TIID/BI	KSC WTR								
TIID/C	KSC WTR	3		2		0		5	
TIID7/C	KSC WTR	0		0		0		0	
TIID7/C/BI	KSC WTR	1		0		0		1	
TIIC	KSC WTR	1		1		1		1 2	
SUB-TOTAL/AGENCY	KSC WTR	11 7	10 13	2 7	2 11	0 6	0 11	13 20	12 35
SUB-TOTAL/YEAR ABORT FLIGHTS		41 4		22 2		17 2		80 8	
TOTAL		45		24		19		88	

TABLE 34. EXPENDABLE LAUNCH VEHICLE TRAFFIC SUMMARY,
BEST MIX EXPENDABLE PAYLOADS, NASA/NON-NASA

EXPENDABLE LAUNCH VEHICLE	LAUNCH SITE	NO. OF LAUNCHES													TOTALS
		80	81	82	83	84	85	86	87	88	89	90	91		
SCOUT	KSC WTR	4 2					4 2							8 4	
DELTA 300	KSC WTR	2 2	3 5	2 2	2 0	2 2	2 2	3 3	2 2	2 3	2 1	3 5	2 3	27 30	
DELTA 900	KSC WTR	1	0	1	1	0	0	0	1	0	0	0	0	4	
DELTA 304	KSC WTR	1	1	0	1	1	1	0	1	1	1	1	1	10	
DELTA 904	KSC WTR			1			2		2			2		6 1	
TIIB/C	KSC WTR	5	3	5	3	1 5	3	1 5	3	5	3	5	3	2 48	
TIID7	KSC WTR	5	0	1	0	1	2 2	4	1 2	0 1	3	0 1	1	18 6	
TIIB/A	KSC WTR	6	2	4	7 1	5	3 1	6 3	5 1	7 3	4 1	5 3	4 1	57 14	
TIIB/C/BI	KSC WTR	1	2	0	1	0	1	1	0	0	0	0	0	6	
TIID	KSC WTR	1 1	1	2	2	3	1	2	1	2	0	4	1	20 1	
TIID/BI	KSC WTR	1		1		1		1		1		1		6	
TIID/C	KSC WTR	4	6	3	6	4	5	7	8	7	8	9	8	75	
TIIM	KSC WTR	2	4	4	4	4	4	4	4	4	4	4	4	46	
TIID7/BI	KSC WTR	1	1	1	1	1	1	2	1	1	1	1	1	13	
TIID7/C	KSC WTR	0	2	0	0	2	0	0	1	0	1	0	1	7	
TIID7/C/BI	KSC WTR	1	1	0	0	2	4	2	0	1	0	1	1	13	
TIIC	KSC WTR	1	2	3 1	1 1	4	2 1	3	1 1	3	2 1	3	1 1	26 6	
TOTAL		40	33	31	31	38	43	47	37	41	32	48	33	454	

TABLE 35. EXPENDABLE LAUNCH VEHICLE TRAFFIC SUMMARY, BEST MIX
EXPENDABLE PAYLOADS, NASA/NON-NASA/DOD

		LAUNCH SITE	NO. OF LAUNCHES												
			80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
DOD		KSC	8	3	6	7	10	4	5	7	7	4	9	3	
		WTR	14	12	12	16	11	17	12	13	12	15	10	14	
	SUB-TOTAL		22	15	18	23	21	21	17	20	19	19	19	17	231
NASA NON- NASA		KSC	29	25	21	25	31	32	36	27	29	26	34	25	
		WTR	11	8	10	6	7	11	11	10	12	6	14	8	
	SUB-TOTAL		40	33	31	31	38	43	47	37	41	32	48	33	454
SUB-TOTAL			62	48	49	54	59	64	64	57	60	51	67	50	685
ABORT FLIGHTS			6	5	5	5	6	6	6	6	6	5	6	5	67
TOTAL			68	53	54	59	65	70	70	63	66	56	73	55	752

VIII. COST ANALYSIS

Based on the capture analysis results and utilizing cost analysis techniques developed by the Aerospace Corporation, Lockheed Missiles and Space Company, and Mathematica Inc., a costing analysis was accomplished for two options. The Expendable Launch Vehicle Case used existing or currently proposed expendable launch vehicles to capture the mission model. The Shuttle System Case accomplished the same mission model using Space Shuttle and Space Tug Systems. The costs for these two options were compared to develop the summary cost information contained in this section.

To assure the comparability of the options, certain ground rules and concepts were incorporated into the options. For example: In the Expendable Case, solid rocket motors were reused and low cost design payloads were used; expendable launches were utilized in the Shuttle System Case to supplement Space Shuttle launches during the buildup period. After assuring comparability of the options in this manner, the cost benefits were assessed.

Table 36 is a summary cost comparison for both the Shuttle and Expendable Launch Vehicles Cases. The Shuttle results in a net benefit of 14.1 billion dollars. Table 37 is the summary cost per user for both the Shuttle and Expendable Launch Vehicle Cases. The non-recurring investment costs are also shown in Table 37. Tables 38 and 39 are further breakdowns of the cost and resulting benefits for each user for the automated and sortie missions, respectively. Table 40 is the summary cost per automated and sortie missions.

Finally, Figure 15 illustrates the effect of the application of various social rates of discount to the net benefits of the cost/capture analysis. Three social rates of discount (5, 7.5, and 10 percent) are computed using the concept of infinite horizon.

The infinite horizon approach simply assumes that the economic payoff period of a new project will continue far into the future, even though the technology of the project continues to change. Details of the infinite horizon concept can be found in Reference 3.

The Internal Rate of Return is computed to be 18.7 percent for the 1973 economic analyses. It is noteworthy that the Space Shuttle System net benefit at a discount rate of 10 percent is still \$4.7 billion.

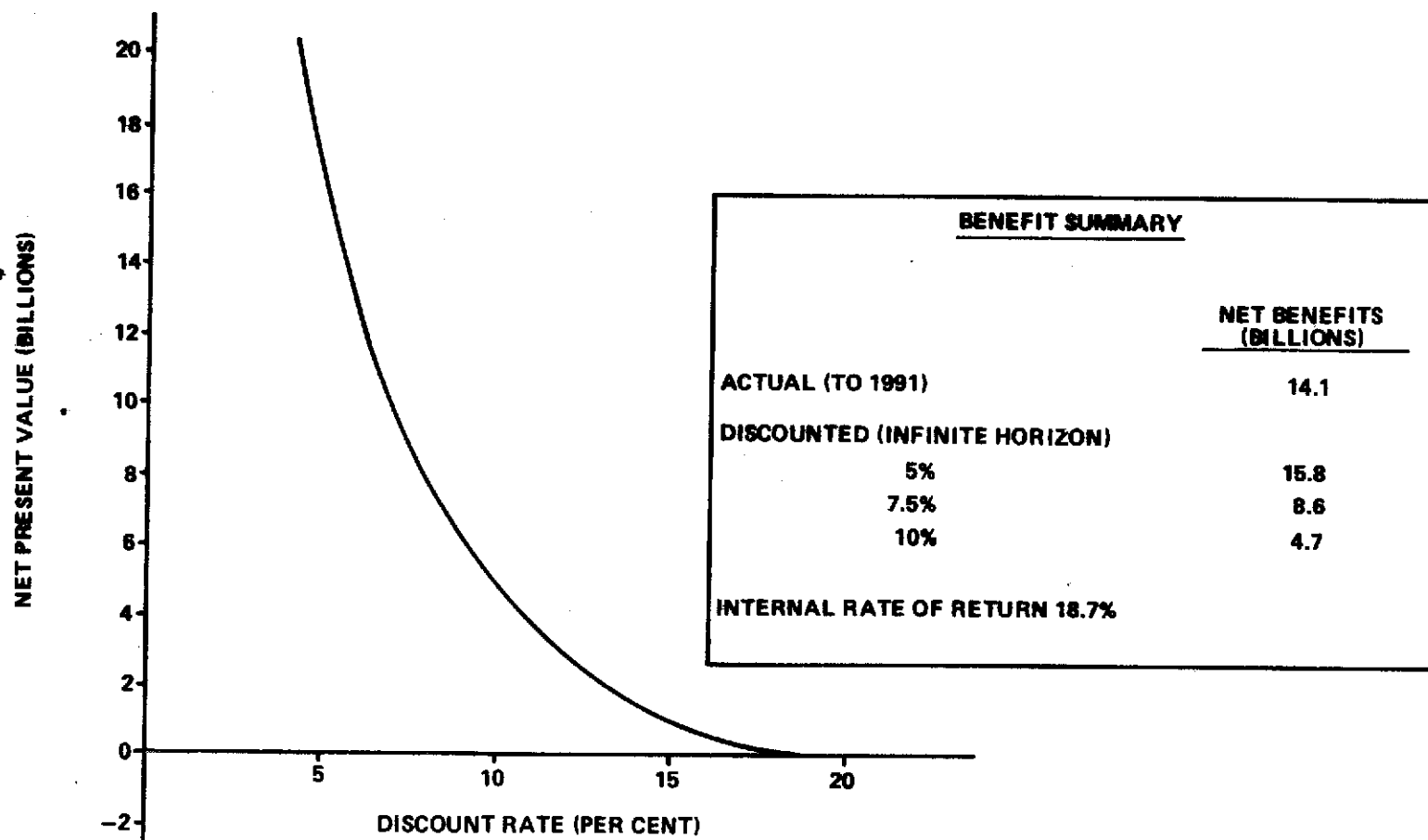


Figure 15. Discounted benefits (1972 dollars, 1972 base year).

TABLE 36. 1973 MISSION MODEL, SUMMARY COST COMPARISON
(BILLIONS OF 1972 DOLLARS)

	Payload	Transportation	Non-recurring Investment	Total
Expendable Case (Best Mix)	46.37	13.22	3.94	63.47
Shuttle Case (Best Mix)	31.65	8.83	8.89	49.37
Benefits	14.66	4.39	-4.95	14.10

TABLE 37. 1973 MISSION MODEL, SUMMARY BENEFIT ANALYSIS (BILLIONS OF 1972 DOLLARS)

	Shuttle System Case	Expendable System Case	Benefits
NASA	22.12	32.24	10.12
Non-NASA	4.53	5.78	1.25
Foreign	1.93	4.19	2.26
DoD	11.71	15.46	3.75
Expendable Launch Vehicle Range Support	0.19	1.86	1.67
Total	40.48	59.53	19.05
Non-recurring Investment	8.89	3.94	-4.95
Grand Total	49.37	63.47	14.10

TABLE 38. 1973 MISSION MODEL, AUTOMATED MISSIONS
BENEFIT ANALYSIS (BILLIONS OF 1972 DOLLARS)

USER	SHUTTLE SYSTEM CASE	EXPENDABLE SYSTEM CASE	BENEFITS
NASA	15.33	19.11	3.78
NON-NASA	4.36	5.50	1.14
FOREIGN	0.59	0.70	0.11
DOD	11.71	15.46	3.75
TOTAL	31.99	40.77	8.78

TABLE 39. 1973 MISSION MODEL, SORTIE MISSIONS
BENEFIT ANALYSIS (BILLIONS OF 1972 DOLLARS)

USER	SHUTTLE SYSTEM CASE	EXPENDABLE SYSTEM CASE	BENEFITS
NASA	6.79	13.13	6.34
NON-NASA	0.17	0.28	0.11
FOREIGN	1.34	3.49	2.15
DOD	0	0	0
TOTAL	8.30	16.90	8.60

TABLE 40. 1973 MISSION MODEL, SUMMARY BENEFIT ANALYSIS
AUTOMATED AND SORTIE (BILLIONS OF 1972 DOLLARS)

USER	SHUTTLE SYSTEM CASE	EXPENDABLE SYSTEM CASE	BENEFITS
AUTOMATED MISSION	31.99	40.77	8.78
SORTIE MISSION	8.30	16.90	8.60
EXPENDABLE LAUNCH VEHICLE RANGE SUPPORT	0.19	1.86	1.67
TOTAL	40.48	59.53	19.05
NON RECURRING INVESTMENT	8.89	3.94	4.95
GRAND TOTAL	49.37	63.47	14.10

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APPROVAL

THE OCTOBER 1973 MISSION MODEL ANALYSIS AND ECONOMIC ASSESSMENT

By Shuttle Utilization Planning Office

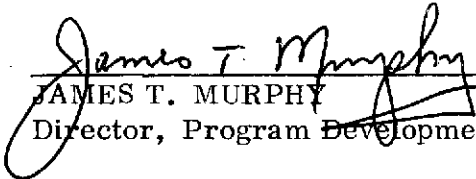
The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.



WILLIAM A. HUFF

Manager, Shuttle Utilization Planning Office
Program Development



JAMES T. MURPHY

Director, Program Development

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